The Effect of Exercise and Physical Activity on Intrinsic Physical Fall Risks

By
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Dissertation submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy

University of Tasmania

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I certify that the thesis entitled

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submitted for the degree of Doctor of Philosophy is the result of my own research. This thesis contains no material which has been accepted for a degree or diploma by the University or any other institution, except by way of background information and duly acknowledged in the thesis, and to the best of the my knowledge and belief no material previously published or written by another person except where due acknowledgement is made in the text of the thesis, nor does the thesis contain any material that infringes copyright. The publishers of the papers comprising Chapters 4 to 7 hold the copyright for that content, and access to the material should be sought from the respective journals. This rest of this thesis may be made available for loan and limited copying in accordance with the *Copyright Act 1968*. The research associated with this thesis abides by the international and Australian codes on human and animal experimentation, the guidelines by the Australian Government's Office of the Gene Technology Regulator and the rulings of the Safety, Ethics and Institutional Biosafety Committees of the University.

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List of Abbreviations

ACSM	American College of Sports Medicine
ANOVA	Analysis of Variance
AP	Anterior-posterior
BOS	Base of Support
CHAMPS	Community Healthy Activities Model Program for Seniors
CI	Confidence Interval
FLX	Flexibility
FROP-Com	Falls Risk for Older People in the Community
ICC	Intraclass Correlation Coefficient
IRR	Incidence rate ratio
OR	Odds Ratio
MET	Metabolic Equivalent
ML	Medio-lateral
nmol	Nano mole
NSAIDs	Non-Steroidal Anti-Inflammatory Drugs
PASE	Physical Activity Scale in the Elderly
PPA	Physiological Profile Assessment
PRT	Progressive Resistance Training
RaR	Relative Risk
RCT	Randomised Control Trial
RR	Relative Rate
RQ	Romberg Quotient
UVB	Ultraviolet Radiation (type B)

Abstract

For older adults, accidental falling produces significant morbidity and mortality, being responsible for personal costs as well as cost to the community at large. The propensity to fall is dependent on a combination of factors that include intrinsic characteristics of each individual as well as environmental influences. Many intrinsic physical fall risk factors are modulated by changes in physical activity levels or exercise interventions. These physical performance fall risk factors include muscle strength, flexibility and balance. The studies that comprise this thesis examine several interventions designed to impact physical fall risk factors, as well as measuring natural seasonal changes in strength, balance and activity in community-dwelling older adults.

The first study (Study I) investigated the benefits on balance of participating in a 16-week community-based resistance and flexibility program in an observer-blinded randomised crossover trial. Static and dynamic balance and lower limb strength were measured. Significant improvements in sway velocity, as well as Timed Up and Go, Ten Times Sit-to Stand and Step Test were observed with both interventions (all $P<0.019$), with no significant differences between the two groups. Resistance training also resulted in significant increases in strength ($P<0.001$), that were not evident in the flexibility intervention.

A subsequent study (Study II) examined the longer term effects of this multi-component exercise program (Study I) on balance, mobility and exercise behavior 12 months after completion. Differences between those participants who continued to

exercise and those who discontinued were investigated. Significant improvements from baseline in Ten Times Sit-to-Stand ($P<0.001$), Timed Up and Go ($P=0.001$), and sway velocity ($P<0.001$) remained at follow up in the exercise intervention group, with a control group remaining unchanged. Participants from the intervention who continued exercising had significantly greater improvements in strength immediately after the intervention, compared to those who discontinued ($P=0.004$). Benefits to balance and mobility persisted one year after participation in the multi-component exercise program, due in part to some continuing participation in resistance training.

The third study (Study III) evaluated the effects of a Pilates intervention on balance and function in 32 participants in a randomised crossover study design lasting 16 weeks. Static and dynamic balance measures (medio-lateral sway range, Four Square Step Test, Timed Up and Go) and leg strength were recorded. There were no significant differences between Pilates and control groups for any of the measured variables ($P>0.05$), despite static and dynamic balance significantly improving over the duration of the study and from pre- to post-Pilates ($P<0.05$), and no significant changes occurring during the control phase. The absence of differences between conditions may be a result of our small sample size or the crossover study design, indicating that Pilates may produce neuromuscular adaptations of unknown duration.

Studies IV and V investigated seasonal variation in lower limb strength and balance respectively in a longitudinal repeated-measures study design concurrently with serum vitamin D and physical activity. Fall incidence, cause and any adverse outcomes were recorded using a monthly prospective fall calendar. Mixed-methods

Poisson regression was used to determine associations between the data. Eighty-eight community-dwelling older adults were evaluated five times over a one-year period.

Significant variation in vitamin D (±15%), physical activity (±13%), ankle dorsiflexion strength (±8%) and hours spent outside (±20%) (all $P<0.001$) was demonstrated over the year, with maximum levels of each measure occurring in January (mid-summer). Quadriceps strength did not change over time (±2%; $P=0.53$). Incidence of falls ($P=0.01$) and injurious falls ($P=0.02$) were lower in spring than in any other season. Postural sway did not vary over the year. Small but statistically significant ($P<0.001$) changes in dynamic balance (4%) were observed over the year. Reduced mean ankle strength was associated with increased incidence of falling ($P=0.047$). Increased ankle strength in summer may be influenced by increased levels of activity over summer months, especially time spent outside. Reduced ankle dorsiflexor strength in winter may predispose older people to increased risk of tripping related falls at this time of year.

The engagement of older-adults in exercise programs and increased levels of physical activity (especially outdoors) have important consequences for addressing age-related decline in aspects of physical functioning related to fall risks. The studies described in this thesis have added to the type of exercise programs that have achieved positive outcomes with randomised-designed studies. This gives older people and health practitioners greater options for exercise, which can be important for uptake and sustained engagement in exercise programs. Additionally the seasonal variation in dynamic balance and ankle dorsiflexion strength are novel findings that practitioners and policy makers need to consider in making recommendations regarding outdoor activity and sunlight exposure for older adults.

1 INTRODUCTION

Accidental falls are a major cause of morbidity and mortality in older adults, and are associated with rapidly increasing costs to both an individual's health and the health care system. The incidence of falling increases as people age, and there are a large number of factors that influence fall rate and type of fall. The propensity to fall is affected by intrinsic characteristics of each individual and their interaction with their environment (extrinsic factors). Although some of these risk factors are not able to be modified, many of the risk factors that pertain to physical functioning have the potential to be modified by physical activity or exercise. These physical performance fall risk factors include; strength, flexibility, balance and integration of sensory information.

Both strength and power decline with natural aging. Reduced strength in the lower limbs is an important fall risk factor, and impacts on daily functioning of older adults. Patterns of muscle recruitment during activities of daily living also alter as an individual ages. While progressive resistance training has been shown to improve strength in older adults, the magnitude of these improvements vary depending on the duration, intensity of, and adherence to the prescribed interventions. However the long-term benefits for older adults of participating in progressive resistance exercise interventions have not been reported extensively and require further investigation.

Balance is defined as 'the ability to maintain or move within a weight-bearing posture without falling' p. 166 (Benjuya et al., 2004). The maintenance of balance is a multifactorial issue, with contributory elements (e.g. vision, reaction time, muscle strength) affected by normal aging processes and/or the presence of acute or chronic illness, as well as medications used to prevent and manage illness. To maintain upright posture while stationary, static balance mechanisms require complex interplay of these contributory elements, and is a dynamic process. Despite the term "static balance" implying that these tasks do not require muscle activity, there is actually constant interplay between opposing muscle groups to maintain a static posture. The addition of movement increases this complexity. To enable responses to self-generated movement, or movement of the environment around a person, dynamic balance systems are required. These systems rely on the co-ordination of sensory information and execution of appropriate motor responses.

Aging affects the way in which people move and respond to external forces, with integration of sensory information altering as the speed of neural processing and number of sensory receptors decrease. These changes result in alterations to both volitional and reflexive motion. Changes to allocation of attentional resources in the prioritisation of challenging activities of daily living are seen functionally as people age (1999, Meher and Oddsson, 2004), although the usefulness of dual task challenges for fall prediction in balance testing has not been conclusively demonstrated (Zijlstra et al., 2008).

Older adults vary in their ability to maintain balance, which may in part be related to the level of participation in physical activity undertaken by different individuals. Basal activity levels have been shown to influence balance characteristics, with both the type and amount of activity being considered important (Gauchard et al., 2003). Cognitive affect and confidence have been shown to influence both activity levels and fall risks. While it is widely recognised that increasing physical activity in the older-aged group will be of benefit, strategies to increase participation in physical activities for older adults have not yet been successful in ensuring that many older adults meet recommended guidelines.

While exercise has been a well-researched area of falls prevention, with Cochrane level evidence of effectiveness for multi-component exercise programs (Gillespie et al., 2009), a relatively poorly researched exercise combination is that of resistance training and flexibility training, both of which have benefits for older adults (Barrett and Smerdely, 2002). Resistance training provides some protection against falling, and mediates one of the most potent fall risk factors – weakness in the lower limb – particularly the quadriceps and hamstring muscle groups and the ankle dorsiflexors (Rubenstein, 2006, Spink et al., 2011a). Resistance training may also alter functional ability by changing recruitment patterns of muscle activation during daily tasks, and this change may underlie improvement in balance and reductions in fall risk. Resistance training programs, with the multitude of health benefits including increases in strength and muscle mass, are gaining acceptability with older adults (Awerbuch, 2001). Despite this, many older adults do not meet the American College of Sports Medicine (ACSM) guidelines for resistance exercise (8-12 repetitions involving all major muscle groups on at least 2 days a week at an intensity of moderate or vigorous) (Chodzko-Zajko et al., 2009). Engaging older adults in appropriate and safe levels of physical activity or targeted exercise remains a challenge for health professionals. Flexibility training is designed to extend or maintain motion around a joint (Salem et al., 2009) and has resulted in some improvements in functional balance tasks as well (Barrett and Smerdely, 2002).

However, the mechanisms underlying changes in balance parameters with flexibility training is not adequately addressed in the current literature and this area is not researched in as much detail as strength training.

Evidence also supports the benefits of specific balance training for all older adults, regardless of risk status (Sherrington et al., 2008). However, while a recent systematic review confirmed the beneficial role of different types of exercise on balance in an older population, there was a degree of uncertainty as to the efficacy of some of the investigated exercise interventions due to a lack of standardised outcome measures to determine balance ability (Howe et al., 2007). Whilst the evidence for benefits derived from interventions that included training activities such as gait, balance, coordination, and functional tasks, general physical activity, strength training, and combinations of exercise modalities was good, the evidence from research which employed single activities such as yoga and dance was less convincing. High level evidence regarding the effectiveness of other exercise regimes, like Pilates, is sparse.

Another moderate gap in the exercise and falls prevention research literature relates to establishing the longer term effects of these exercise interventions, beyond the formal structured exercise program duration. Determination of the effectiveness of exercise programs to make long term improvements in physical performance is important for cost-effective provision of services. Motivation for older adults to exercise includes the prospect of staying independent and improving physical balance (de Groot and Fagerstrom, 2011). Ongoing motivation to continue exercise is complex, and identification of factors which enhance maintenance of changed exercise and activity behaviours can be used in design of programs and support for individuals to improve health outcomes.

Finally, important factors that can influence balance performance and muscle strength, as well as fall risk, that have not been examined for their effect on balance and physical outcomes serially over time together, are vitamin D, sunlight exposure, and physical activity levels. These three parameters interact in a complex manner to reflect function within individuals (Birrell and Francis, 2008). The effect of background seasonal variation in physical activity, especially outdoors physical activity and its impact on physical risk factors (balance and strength) are not known. Whether or not recordable seasonal variation in these variables exists, knowledge of the natural seasonal variability will enhance clinical assessment decision making and research interpretations.

The series of studies comprising this thesis aim to add knowledge to these identified research gaps. Specifically, the primary research aims of the studies in this thesis were to:

- Determine the effect of resistance and flexibility exercise interventions on measures of balance and physical performance (Chapter 4)
- Determine the ongoing effect of resistance and flexibility exercise interventions a year after the intervention, and the factors that contribute to adherence to changed exercise behaviours (Chapter 5)
- Determine the effect of a Pilates based exercise program on balance and physical performance measures (Chapter 6)

- Identify seasonal variation in balance, physical performance measures, vitamin D, falls, activity and sun exposure in older adults living at a high latitude (Chapters 7 and 8).

2 LITERATURE REVIEW

2.1 *Fall risks*

2.1.1 Fall rates

The World Health Organisation defines a fall as 'an event which results in a person coming to rest inadvertently on the ground or other lower level' (www.who.int/violence_injury_prevention/unintentional_injuries/falls/falls1/en). Falling amongst older adults is a common occurrence, and the rates vary depending on the situational context of the setting. Epidemiological studies in North America have found an annual fall rate among adults living at home aged 65 years or older of 30% (O'Loughlin et al., 1993), increasing for those who live in residential care (Rubenstein, 2006). A prospective population based Australian study has reported similar results with 39% of the community-dwelling older adults (over the age of 65) studied experiencing at least one fall over a 12 month period (Lord et al., 1993). Half of those people who fall each year will only report one fall for the 12 month period, but the other half will report falling multiple times (Tinetti and Williams, 1998).

Between 6% (Nevitt et al., 1991) and 10% (Tinetti, 2003) of falls in the over 65 age group result in serious injury. In Australia in 1993, falls were identified as the cause of 42% of injury-related deaths in community-dwelling older adults (Dolinis et al., 1997). Among community-dwelling older adults, five per cent of falls have been reported to result in a fracture (Rubenstein, 2006). Even in healthy female volunteers (mean age 74±4 yrs.) who had been screened for medical problems that would affect balance or mobility, Hill reported 50% fall rate and 10% fracture rate in one year (Hill et al., 1999). Ninety per cent of hip fractures result from falls, and outcomes are generally poor, with 25 per cent of patients requiring nursing home admission (Magaziner et al., 1990). At one year post-hip fracture the resultant mortality is twenty-three per cent for women, and thirty-one per cent for men (Wehren et al., 2003). Regardless of injury, there are also concomitant reductions in quality of life and independent functioning reported after a fall. Reductions in activity and fear of falling are common sequellae (Tinetti and Williams, 1998). Physical deconditioning, a longer term effect of activity restriction, increases fall risks further.

It is anticipated that the health care cost of increased number of falls (due to increased number of older adults) will place huge demands on the system in the future. In 2003, the Commonwealth Department of Health and Aging (Moller, 2003) reported a projected tripling in annual costs of injury from falling to $1.375 billion by the year 2050, if fall rates remain unchanged over this period.

Identification of at risk people-screening versus assessment

Public health funding directed at identification of people at risk of falling needs to be strategically managed. Implementation of effective strategies to minimise falls begins with identification of those people who are at risk of falling. Some fall risk factors, such as balance and walking problems, are evident before a fall has occurred and the screening process is designed to identify these risks. Screening of older people (>65 years) who may be at risk by an appropriate health professional, is a practical method of identifying the presence of underlying factors that may need to be addressed.

There are various reasons why people fall; some related to postural instability, and others related to more serious underlying medical conditions that should be investigated if the reason for the fall cannot be ascertained. The reasons for a fall occurring are often multifactorial, with both environmental and person-specific factors interplaying. Although about 40% of falls are attributed to tripping, at least 25% have been reported to be the result of poor physical performance, specifically poor balance (21%) or low leg strength (6%) (Lord et al., 1993).

A clinical algorithm that outlines a pathway for strategically determining who will benefit from a multifactorial assessment has been developed (Kenny et al., 2011). It uses basic screening questions to identify an appropriate clinical pathway for older adults presenting to a health professional, and may or may not lead to further assessment. The questions cover fall history (single or multiple falls within the last twelve months) and difficulty with walking or balance. Asking people if they have had a fall, may be a useful screening question to identify individuals who may benefit from advice to reduce their future fall risk. A single faller should have gait and balance assessed. If these are within normal limits, no immediate further action is required. Multiple fallers and single fallers who present with a walking or balance disturbance will benefit from a multifactorial assessment of fall risk. Individuals with balance or gait problems, even without a fall, would benefit from a multifactorial fall assessment (Kenny et al., 2011). Testing of the usefulness of this algorithm in different clinical populations is being undertaken; appearing effective for those with high risk but the prognostic value for those at low risk not being demonstrated recently (sensitivity of 0.50 [95%CI 0.36 to 0.64] and specificity of 0.82 [95%CI 0.70 to 0.90]) (Muir, 2010).

Referral to a falls clinic or service allows for multi-factorial assessment of individual fall risk factors, with the subsequent ability to tailor appropriate interventions to that person. Preliminary evidence suggests that fall clinics are effective in producing improvements to balance and balance confidence, leg strength and gait speed, with high adherence to interventions of 74% reported (Hill et al., 2008). Although falls clinics are becoming more available, there is still limited access for many older people, and assessment by a relevant health professional may be a strategic way of meeting the fall assessment needs of a larger number of people.

The ability to apply a community based test to assess balance and gait disorders for people who have not yet fallen is a useful goal, with the subsequent ability to determine if multifactorial assessment is required, and consequently provide interventions that may prevent future falls. One test, The Timed Up and Go test (TUG), is a simple measure of function that requires both adequate leg strength and dynamic balance, and has the ability to discriminate between fallers and non-fallers in a community-based setting (Shumway-Cook et al., 2000). Despite this, it does not give any indication where within the postural stability system a deficit exists. A score of over fifteen seconds is recommended by both the American and British Geriatrics Societies (Panel on Prevention of Falls in Older Persons, 2011) as a useful filter level for identifying those individuals who would benefit from more extensive evaluation of their possible impairments.

Multifactorial assessment

If, after screening, a person is identified as requiring a multifactorial assessment, a panel from the American and British Geriatric Societies (Panel on Prevention of Falls in Older Persons, 2011) have identified that the following items should be included in that process:

- History of falls
- Medications
- Gait, balance and mobility
- Visual acuity
- Neurological impairments
- Muscle strength
- Heart rate and rhythm
- Postural hypotension
- Feet and footwear
- Environmental hazards.

In addition, a relevant medical history and assessment of physical and cognitive function should be included in this assessment process.

A number of validated multifactorial fall risk assessment tools are available. Several examples of these have been developed in Australia and validated to provide assessment of individuals by an allied health professional in community or outpatient settings. *Quickscreen*© has been developed as a tool to assess neurosensory (tactile and visual acuity), and motor components (functional leg strength, reaction time and balance) in addition to fall history and medication use, to gain a fall risk score (Lord et al., 2007). A benefit of the *Quickscreen*© over a simple mobility screen such as the TUG is that it provides component specific information to target remediation, while being relatively quick (ten minutes) and portable (Lord et al., 2007).

A more detailed (in terms of both time and equipment) series of tests have been developed by the same research group to assess age related sensorimotor and balance changes that provide more quantitative information about important physiological fall risk factors (Lord et al., 2003b). The Physiological Profile Assessment (PPA) is a validated measure of fall risk that allows identification of the core physiological components (cutaneous sensation, vision, vestibular sensation, strength and reaction time) that contribute to physical fall risk. However, it does not include other important fall risk factors such as incontinence, cognitive impairment, or polypharmacy.

A comprehensive screening tool that is appropriate for community-dwelling older adults is the Falls Risk for Older People in the Community (FROP-Com) tool (Russell et al., 2009). It takes a minute or two to implement, and usefully stratifies people into low or high risk – indicating if further assessment and multi-factorial interventions are required. This quick tool is useful to identify people at higher risk, however may not be sensitive in meeting the needs of low risk people, as fall risks occur on a continuum.

In summary, accidental falls in older adults are common, and result in considerable impact on an individual's well-being, with wider implications for our whole society. Screening, with targeted multi-factorial assessment and intervention for those identified at risk may help reduce personal and community costs.

2.2 *Factors affecting fall risk*

Falling is influenced by both internal or intrinsic factors that are specific to an individual, and external factors that pertain to the environment. A multifactorial cause is most common, with the interrelationship between more than one risk factor being responsible for a fall. This section of the literature review will focus on intrinsic fall risk factors in community-dwelling adults, with a particular emphasis on those physical performance factors that can be modified. Strength and balance are strong independent risk factors for falls (Rubenstein, 2006). **Figure 2-1** identifies the intrinsic fall risk factors and describes the relationship between factors that are either potentially modifiable (i.e. strength, balance and activity) or non-modifiable (i.e. gender, genetics and having a previous fall). It is based on information from Hill and Murray (2004). Modifiable factors have been categorized in terms of their dependence on physiological or psychological systems. Some of these factors combine to form independently identifiable risk factors, for example a combination of sensory or strength factors will influence gait with gait disturbance identified by Rubenstein & Josephson (2006) as one of the four strongest risk factors for falling with an odds ratio of 2.9 (Confidence Interval 1.3 to 5.6).

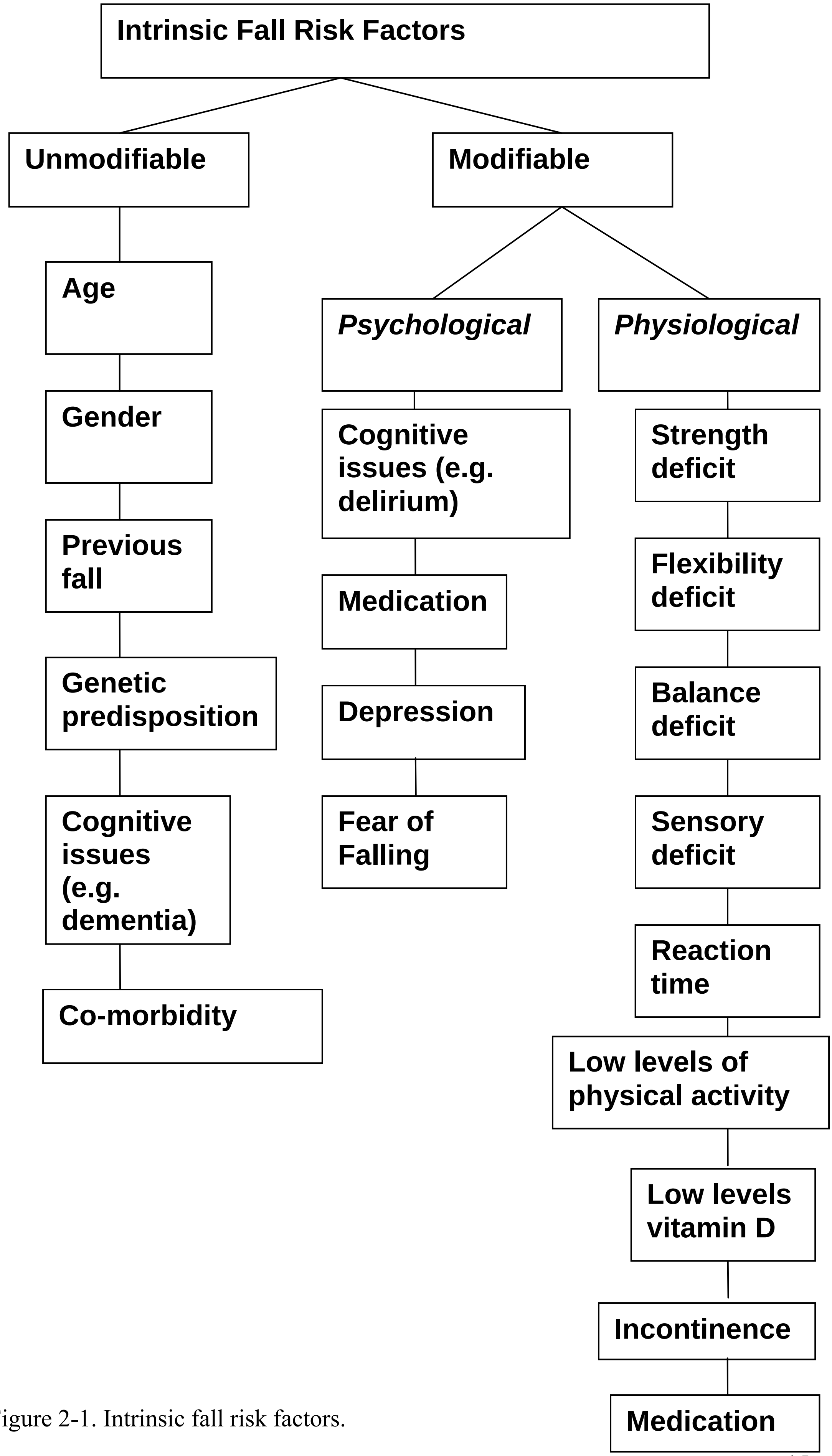

Figure 2-1. Intrinsic fall risk factors.

Of these intrinsic fall risk factors, many are potentially amenable to change through increasing the level or type of physical activity performed. These risk factors include:

- Leg muscle weakness
- Impaired balance
- Reduced reaction time
- Leg muscle flexibility
- Low levels of physical activity.

2.2.1 Age

The incidence of falling and the associated severity of falls both increase with age. Concurrently, fall related mortality increases with age (Rubenstein and Josephson, 2006). Lord and colleagues reported a roughly linear increase in the number of older people falling, proportional to increasing age, resulting in an annual incidence of falling of over 50% for people aged above 85 years of age (1993). This increased fall risk with age is due in part to age specific decline in the systems required for adequate balance control (vestibular, visual, somatosensory, motor control and strength).

These multisystem changes have been identified to be apparent as early as the mid-forties (Isles et al., 2004). Changes to the areas of the body affected by falling appears to transition from the 65-75 age group where wrist fractures are the most common type of fracture, to a predominance of hip fractures in the over 75 year age group (Rubenstein, 2006), perhaps coinciding with changes to postural strategies and response times.

2.2.2 Gender

Gender is an unmodifiable risk factor for falling (Nachreiner et al., 2007). Women have been found to be more likely to fall than men (64.7 % compared to 44.1%) in a study where 94% of participants lived in their own homes (Campbell et al., 1990). This is further supported by a more recent study in the United States which found that over 70% of 1.64 million fallers in that country in 2001 were women (Stevens and Sologow, 2005). As well as the increase in the incidence of falling, the fracture rate from falling in women was 2.2 times that of men (Stevens and Sologow, 2005). Differences in physiology and bone architecture mean that the implications of falling are different, as are the perceptions and attitudes of men and women to causality and the ability to modify fall risk (Daltroy et al., 1999). Contextually, men are more likely to fall outside the house, whereas it is more common for women to fall inside the house (Campbell et al., 1990).

2.2.3 Previous falling

Previous falling is a strong risk factor for further falling, and provides useful information to be used in screening to determine the need for further fall risk assessment (Panel on Prevention of Falls in Older Persons, 2011). Self-imposed physical limitations on activity, often the sequellae of an initial fall, can result in an increased falls incidence (Tinetti et al., 1994). Moderation of physical activity produces a negative spiral which increases fall risk through deconditioning, affecting both strength and balance mechanisms. The incidence of multiple falls in older adults (over 62 years) is high, with numbers being variously reported in the literature as 22% in community-dwelling women (n=307) (Bergland et al., 2003) and 23% for men and women living independently in shared apartments (n=100, 83% female) (Maki et al., 1994).

2.2.4 Genetic predisposition

In a study of postural balance of both monozygous and di-zygous female twins, 30 per cent of the variation in static, dynamic and sensory balance measures were accounted for by genetic effects (El Haber et al., 2006). These results imply that balance impairments may have a heritable element and this may be functionally important, with moderate familial influences on fall-risk mobility phenotypes and recurrent falls found in older females (71.9 ± 5years) (Faulkner et al., 2010).

2.2.5 Co-morbidity

Concomitant health issues, both chronic and acute, affect balance and falling. Apart from intrinsic fall risk factors that result from the normal aging processes, some medical conditions substantially increase risk of falls (Speechley, 2011). Chronic medical conditions that impact on postural stability and falling include those that impede normal sensory perception, those that control processing of that sensory input, and those involved in executing an appropriate effector response. Musculoskeletal conditions, including arthritis, are common fall risk factors (Foley et al., 2006), and neurological based medical conditions like Parkinson's disease (OR 2.7) (Deandrea et al., 2010), cerebro-vascular accidents and dementia (Speechley, 2011) have been shown to be intrinsic fall risk factors. Cardiovascular conditions, such as postural hypotension and carotid hypersensitivity, are also common medical causes of falls (De Breucker et al., 2007). The presence of more than two co-morbidities increases the risk of falling, with odds ratios (adjusted for age) provided by Dolinis and colleagues (1997) (**Table 2.1**).

Table 2-1. Increasing fall risk with increasing number of co-morbidities.

Number of co-morbidities	**Odds Ratio (95%CI)**
3-5	1.35 (1.00 to 1.84)
6-8	1.73 (1.25 to 2.38)
>9	1.92 (1.31 to 2.82)

Sourced from **(**Dolinis et al., 1997)

2.2.6 Cognitive Issues

Functional ability is strongly associated with cognitive processing speed (Wood et al., 2005). Increasing cognitive load while performing activities that may challenge balance, especially with spatial tasks, increases the risk of falling (Barra et al., 2006).

Dementia has an incidence of between 6% and 10% in adults over the age of 65 in North America (Hendrie, 1998). Fall rates amongst people with Alzheimer's disease living in the community are higher than similar-aged populations living in the community (42.4%) (Horikawa et al., 2005). Many studies in community settings exclude people with cognitive impairment, and some fall prevention strategies that are effective for general older adults, do not appear to be effective when concurrent cognitive impairment is present (Shaw, 2003). Despite this, a review of balance and physical performance measures in people with dementia identified four exercise intervention studies with enough detail provided to calculate effect size for balance and strength improvements (Suttanon et al., 2010). For balance measures the effect size ranged from no effect 0.07 (95%CI -0.62 to 0.76) to large 3.29 (95%CI 2.17 to 4.41). This range of results limits the ability to draw conclusions about the overall effectiveness of exercise interventions in people classified generically with dementia. It is likely that the different subgroups of types of dementia may respond differently to exercise interventions, and this warrants further investigation.

Acute cognitive disordered states, such as delirium, that may be triggered by metabolic imbalance or uncontrolled infection, also put older people at increased risk of falling (McCarter-Bayer et al., 2005). The incidence of delirium is linked to cognitive capacity, and has been reported in 12% of urology cases (Vollmer et al., 2010), 16% after cardiac surgery (Kazmierski et al., 2010), and up to 45% of patients in critical care units (Shi et al., 2010). In the acute care setting, the presence of delirium increased the risk of falling significantly (RR=3.577; 95%CI 1.096 to 11.672) (Corsinovi et al., 2009).

2.2.7 Medications

As people age, changes to the way in which they metabolise drugs, along with the emergence of comorbidities, provides a complex interplay of factors which can lead to adverse effects from medication use (Boyle et al., 2010). Polypharmacy refers to the concurrent use of multiple medications (usually 4 or more), and this is a common situation in the health management of older adults. In the United States, 40% of older adults take more than five medications per day (Kaufman et al., 2002). Polypharmacy has been repeatedly shown to be strongly related to fall risk (Greene et al., 2010, Rubenstein, 2006). Four or more medications increase the risk of one fall (OR 1.3, 95%CI 1.0 to 1.7) and multiple falls (OR 1.5, 95%CI 1.0 to 2.3)

(Tromp et al., 2001). Optimisation of medications was advised as part of the intervention in 22 out of 30 trials described in the most recent Cochrane Systematic Review of multifactorial interventions for fall prevention (Gillespie et al., 2009).

Psychotropic drugs refer to those classes of medications that are active within the central nervous system and include antipsychotics, sedatives, antidepressant and narcotics. A recent meta-analysis reported significant increases in the risk of falling when using psychotropic medications, pooled across all classes of drugs (OR 1.78, 95%CI 1.57 to 2.01) (Bloch et al., 2011). Prescription of these groups of drugs is common in older adults, often for anxiety and sleep disorders. In a randomised control study, removal of psychotropic drugs resulted in a reduction in fall risk of 66% (Campbell et al., 1999b). Although this benefit is clear, ceasing psychotropic medication is difficult, and 47% of the trial participants had recommenced their medication within one month of the trial completion, suggesting prudent use of initial prescription of these medications, and ongoing support to remain off these medications long term to positively impact fall risk.

Other classes of medications, including cardiac and anti-inflammatory medications, have also been shown to increase fall risk (Woolcott et al., 2009), and the results of this review are included in **Table 2-2**. Although an early study found that use of non-steroidal anti-inflammatory medications (NSAIDs) was associated with a reduced rate of falling (Gluck et al., 1996), several more recent studies have reported an increased rate of falling (Kallin et al., 2004), with the most recent (Walker et al., 2005) identifying a ten-fold increase in fall risk amongst hospitalised patients on

NSAIDs. Ensuring that medications are reviewed and adjusted regularly may be effective in reducing falls (Gillespie et al., 2009).

Table 2-2. Fall risk associated with medication use.

Drug Type	**Unadjusted Odds Ratio (95% CI)**
Antihypertensives	1.24 (1.01 to 1.50)
Diuretics	1.07 (1.01 to 1.14)
B-blockers	1.01 (0.86 to 1.17)
NSAIDs	1.21 (1.01 to 1.44)
Sedative	1.47 (1.35 to 1.61)
Antipsychotics	1.59 (1.37 to 1.83)
Antidepressants	1.68 (1.47 to 1.91)
Benzodiazepines	1.57 (1.43 to 1.72)
Narcotics	0.96 (0.78 to 1.1.8)

Sourced from (Woolcott et al., 2009).

For patients who have other known risk factors for falling (gait and balance disturbances, peripheral neuropathy or postural hypotension), drugs that are known to increase fall risk should be prescribed and used with caution (Boyle et al., 2010).

2.2.8 Depression

Depression is associated with falling (Vind et al., 2010) and severe depression is associated with repeated falling (Nevitt et al., 1989). In a population based study, the prevalence of depression in women was found to be 6.3%, and women with depression were more likely to subsequently have a fall (OR 1.6, 1.3 to 1.9) (Whooley et al., 1999). Both Lui and colleagues and Woolcott and colleagues found that the use of antidepressive medication increased fall risk by about 60% (Liu et al., 1995, Woolcott et al., 2009). Depression can be positively impacted on by both exercise and increased levels of general physical activity, with aerobic and resistance training both producing large effects in affect (Biddle and Fox, 2000). Direct impact of exercise on fall risk in patients suffering from depression does not appear in the literature. Objectively measured changes in physical performance post-exercise are also important to psychological well-being (Arent et al., 2000). Higher levels of physical activity have been found to be protective of all-cause depression (Strawbridge et al., 2002).

2.2.9 Incontinence

Incidence of incontinence increases with age from the fifth decade (12.7%) to the ninth decade (33.8%) (Komesu et al., 2009), but this appears higher in industrialised countries, with rates for women up to 55% (Thom, 1998). Incontinence is an independent risk factor for falls (Brown et al., 2000) and recurrent fallers are more likely to suffer from incontinence (OR, 1.7; 95%CI 1.0 to 2.7) (Van Nieuwenhuizen et al., 2010). Incontinence appears to be a modifiable fall-risk factor with evidence from a RCT using a multi-dimensional 3 month exercise program as the intervention and found both decreased levels of incontinence from 67% to 23% and increased walking speed in older women (Kim et al., 2011). Situational links with incontinence and falling have been recognised, perhaps due to night time diuresis and low levels of lighting (Yasumura et al., 1994).

2.2.10 Fear of falling

Self-efficacy is defined as an individual's judgement or perception of their ability to organise and execute specific tasks or performances (Bandura, 1977), and is considered a better predictor of activity than actual physical capacity. In relation to physical tasks that challenge balance, falls self-efficacy (sometimes referred to simply as falls efficacy) relates to the confidence of an individual in their ability to perform that task without falling. This is sometimes referred to as fall confidence, and is the opposite of fear of falling.

Nearly one fifth of community-dwelling older adults surveyed in a study by Tinetti and colleagues (1994) recorded that they avoided certain activities because they were concerned that they may fall. This rate may be low by today's standards with a recent study by Zijlstra and colleagues (2007) of community-dwelling adults over seventy years of age reporting that 54.3% of participants recorded a fear of falling and that this was associated with avoidance of activity by 37.9% of the sample population. Activity avoidance can result in loss of functional ability through deconditioning of muscles. Although initially thought to be due to a consequence of a previous fall, 12-65% of adults in their sixth decade without a history of falling will report a fear of falling (Legters, 2002). Low mobility is associated with fear of falling in the absence of a previous fall (Chandler et al., 1996).

Self-efficacy and balance, measured by postural sway, are strongly correlated (P=0.02) (Liu-Ambrose et al., 2006). Measurement of self-efficacy remains contextual; people may say they have no fear of falling if they do not have to leave their house, but may report a high fear of falling if they have to go outside. Although sometimes measured as dichotomous (do you have fear of falling during a range of activities – yes/no) in reality this variable occurs on a continuum. Several validated scales, for example, the Activity specific Balance Confidence (Powell and Myers, 1995), Fall Efficacy Scale (Tinetti et al., 1990), the Modified Falls Efficacy

Scale (Hill et al., 1996b) and the Falls Efficacy Scale International (Yardley et al., 2005) have been developed to measure this variable across the continuum of fear to confidence, and in a range of situations with graduated difficulties. Exercise (including Tai Chi) appears as the most promising single factor intervention to improve balance confidence, and the concurrent activity limitations that often coincide with fear of falling (Bula et al., 2011).

2.2.11 Muscle Strength

Reduced muscle strength of the lower extremities has been shown to be an important fall risk factor. A meta-analysis of thirteen studies (9 of which were situated in community settings) indicated a combined odds ratio of 1.76 (95%CI 1.31 to 2.37) for low muscle strength for any fall and 3.06 (95%CI 1.86 to 5.04) for recurrent falls (Moreland et al., 2004). More recently Rubenstein (2006) reported leg weakness, measured either by manual muscle examination or functional testing, was associated with an increase in the odds of falling by more than four times (4.9), making lower limb weakness 'most important of these risk factors'p.ii39. This held true regardless of age, as the studies included a range of ages, with 50% of the participants being over the age of 65.

In this context, lower limb weakness includes strength in a range of directions around the knee and ankle. Decreased knee extension strength was also age independent in a group of fallers compared to non-fallers in a group of frailer older people (age 79.5±6.4 years; n=1762) (Lord et al., 2003b). As well as ankle strength, foot posture has been found to be an important determinant of balance and functional ability in older adults, particularly plantar flexion strength of the hallux (Spink et al., 2011a). In addition, weakness of the ankle dorsiflexors has been associated with an increase in fall risk (Wolfson et al., 1995).

Motor changes with ageing

The domain of motor output includes strength and power, as well as co-ordination of groups of muscles. Muscle mass decreases by 50% between the ages of 20 and 90, with an associated increase in fall risk (Schlicht et al., 2001). Between 30 and 40% of this muscle mass is lost between the ages of 20 and 70 years, with corresponding declines in muscle strength (both maximal force and power) reported (Brooks, 1994). Both age-related sarcopenia, and sarcopenia due to disuse atrophy affect the cross-sectional area of the muscle. Aging also results in reductions in the number of muscle fibres, as well as a decrease in expression of Vitamin D receptors on muscle cells (Bischoff-Ferrari et al., 2004a), both of which may play an important role in age-related muscle strength loss.

A review of literature on selective loss of muscle fibre type by Taffe (2004) indicates some disparity between studies with type II fibres either being lost in a higher proportion, or having lost significantly more of the muscle cross sectional area than type I. Healthy older adults have lower scores on leg strength measures (between 20 and 40 per cent) when compared to young adults (Rubenstein, 2006). These changes are attenuated in older individuals who have participated and maintain participation in strength or endurance training, in terms of both fibre type, composition and the ability to develop force at a higher rate (Aagaard et al., 2007). A decrease in the number of cells in the anterior horn of the spinal column of older adults as well as a decrease in the number of motor units will affect motor control, although the age-related loss of motor units precedes changes in actual strength by several decades (McNeil et al., 2005).

Intramuscular metabolic responses to exercise also change with aging. Differences exist between young and older adults in the genetic expression of peptides responsible for stimulating stem cells and the resultant hypertrophy of muscle (Goldspink, 2007). Recent evidence provided from animal models suggests that vitamin D has a role in satellite cell differentiation within muscles (Dirks-Naylor and Lennon-Edwards, 2011), while lower levels of vitamin D are associated with less muscle mass in older adults (Scott et al., 2010).

Hip and ankle muscle recruitment differences between young and older adults in functional tasks

In a variety of daily tasks, including sit-to-stand, gait and postural stability maintenance, older adults differ to younger adults in the way in which they recruit muscles to manage internal and external forces. Older adults flex their trunk, hips and knees more than younger adults during sit-to-stand tasks (Schot et al., 2003) in an attempt to minimise the horizontal distance that the centre of mass must move to be re-positioned over the new base of support (also known as the stabilisation strategy).

Flexion is also seen at the hip and trunk in older adults during gait with a significant decrease in hip extension moment in older fallers (Kerrigan et al., 2000) compared to similar aged non-fallers. Stabilisation strategies require adequate strength in the extensor muscles of the legs – primarily the quadriceps group, whereas some older adults utilise momentum, which may require less overall strength, but actually has greater postural control demands (Schot et al., 2003).

Nashner and McCollum (1985) describe a frequently used strategy that focuses on activation of the hip muscles (hip strategy) that is used preferentially by older adults when their balance is challenged. This contrasts with younger individuals, who more commonly reflexively activate muscles around the ankle (ankle strategy) to maintain their balance. Responses differ depending on the magnitude of the perturbation, the stance parameters of the task (narrow or wider base) and support surface (firm or soft). Reasons for age-related differences are based on changes to both the amount of sensory information available to the central nervous system, how it is perceived and the manner in which this information is processed, and the musculoskeletal resources that are available for response - all factors which alter as individuals age. The importance of the role of pelvic muscular control in the maintenance of postural stability is demonstrated by the similar amplitude of lumbosacral and ankle sway in the coronal plane (out of phase by pi) (Jiang et al., 2006).

Compensatory stepping may be the only recourse in response to large perturbations (Maki and McIlroy, 2006), and older adults will often preferentially choose this strategy at lower levels of instability, compared to younger adults (Jensen et al., 2001). The change from use of ankle muscles (primarily tibialis anterior) to use of more proximal muscles to maintain stability appears to be due in part to changes in the muscle latency time when the body sways backwards, which is increased in older adults (Amiridis et al., 2005).

Co-contraction strategies are used more frequently in older adults (aged 67.5±1.7) when compared to a younger group (aged 29.6±2.5 years) (Spiegel et al., 1996). The ability to make quick and involuntary compensatory steps in response to self-generated or externally generated perturbations is usually present in healthy older adults (Luchies et al., 1999). With decreasing lower limb strength, there is an increase in the number of steps taken to recover balance, perhaps because the torque of the muscles required for stability around the hip and knee may not be adequate (Maki and McIlroy, 1999). This has implications for the dynamic balance requirements of a range of functional activities and lower limb strength training.

2.2.12 Ankle flexibility

Flexibility and range of movement at the ankle has also been shown to be important for balance (Menz et al., 2005). This is especially true in the inversion/eversion direction (Spink et al., 2011a). In a RCT, a multi-factorial intervention which included ankle and foot flexibility and strengthening exercises together with footwear modifications reduced the number of falls by 36% compared to the control group, who received usual podiatric care only (incidence rate ratio 0.64, 95%CI 0.45 to 0.91, P=0.01) (Spink et al., 2011b). The reduction in falls occurred with concurrent improvements in ankle range of motion in the intervention group.

Age-related changes in flexibility, generally, are the result of changes within connective tissue and joints, resulting in loss of range of motion as people age (Holland et al., 2002). It is not possible with current literature to separate out the effects that result from disuse, and the impact of a range of physiological conditions that affect the musculo-skeletal system of adults as they age.

2.2.13 Balance

Definitions of Balance

Balance is defined as 'the ability to maintain or move within a weight-bearing posture without falling' p. 166 (Benjuya et al., 2004). Functionally, balance is required in three different ways:

- For the maintenance of posture (when no overt movement is occurring). This is a static balance role;
- For controlling movement of the center of mass (COM) during activities of daily living, such as turning, stepping or reaching when destabilising forces have been generated internally (dynamic balance control);
- In response to external destabilising forces such as trips or slips to maintain or return the COM to the area over the base of support, or take a step to return equilibrium (dynamic balance control) (Berg et al., 1989).

Balance forms the foundation for everyday voluntary motor skills (Massion and Woolacott, 1996), and this is true both in maintaining stationary positions over a variety of support configurations and during activities of daily living. Daily activities that require dynamic balance control require re-positioning of the COM over the BOS while moving at different speeds in different directions, such as twisting, bending, or reaching. It is more common for falls to occur while performing these daily tasks than while performing higher risk activities, like ladder climbing (Nevitt et al., 1991). When the COM moves towards the outer limits of the BOS with the feet stationary, compensatory internal adjustments must be made and, if not sufficient to maintain stability, a compensatory step must be taken to prevent a fall.

During more dynamic tasks, such as walking, the COM needs to be maintained within limits so that it will flow over the new base of support (Huxham et al., 2001). Internal forces need to be generated to balance torques generated either from within or external to the body to maintain equilibrium. The amount of force required is dependent on the mass of the body parts in motion and the speed of this motion – it is easier to recover equilibrium from a trip when moving more slowly compared to faster walking speeds (Huxham et al., 2001).

Measurement of Balance

Balance can be measured in a variety of ways based on combining motion of the BOS (moving or stationary) and differing biomechanical and sensory demands (Huxham et al., 2001). One manner of categorization is through measurement of either static or dynamic balance. Although relying on the same structural components, control of static and dynamic balance relies on different mechanisms for their maintenance. A comprehensive assessment of balance status will include assessment of both of these, and a combination of tests is recommended to provide information on balance and fall risk (Bernhardt and Hill, 2005).

There are a large number of clinical and laboratory (force platform) tests of balance performance (Huxham et al., 2001). Some frequently used measures of static balance are included in **Table 2-3** and those for dynamic balance in **Table 2-4.**

Table 2-3. Commonly used measures of static balance

Static Balance	**Measure**
Single limb stance	Timed (Bohannon et al., 1984)
Tandem stand	Timed (Speers et al., 1998)
Postural sway (eyes open and closed)	Velocity or displacement (Lord et al., 2003b)
Postural sway (firm and foam surface)	Velocity or displacement (Lord et al., 2003b)
Postural sway (dual task)	Velocity or displacement (Condron and Hill, 2002)

Table 2-4. Commonly used measures of dynamic balance

Dynamic Balance	**Measure**
Internal perturbation	Functional Reach(Duncan et al., 1990)
	Lateral Reach(Brauer et al., 1999)
Internal perturbation (single limb stance)	Four Square Step Test (Dite and Temple, 2002a)
	Step Test (Hill et al., 1996a)
External perturbation	Pastor's test (Morris et al., 2000, Frzovic et al., 2000)
	Postural Stress Test (Wolfson et al., 1986)
Combination tests	Berg (Berg et al., 1989)
	Tinetti (Raiche et al., 2000)
	Performance Oriented Mobility Assessment (Tinetti, 1986)
	Balance Outcome Measure for Elder Rehabilitation (Haines et al., 2007)
	Balance Evaluation Screening Test (Horak et al., 2009)

Postural sway parameters

In quiet standing there are spontaneous variations in the position of the centre of mass, which can only be measured indirectly, by recording the vertical component of the ground reaction force using a force platform. This spontaneous motion is defined as postural sway.

There are several commonly used parameters of postural sway that have been reported in the literature, including the velocity of the movement of the COM, total path of the COM within a set time frame, and range of displacement of the COM in both the anterior-posterior (AP) and medio-lateral (ML) directions (Era et al., 2006).

Sway velocity

Velocity of movement of the COM is usually measured in degrees per second, and needs consideration of the height of the subject. Taller subjects have a higher vertical height of the COM and this will impact on the resultant measures of sway velocity at the force platform. Sway velocity has been shown to be reliable in identifying both fall risk and age related changes to balance (Raymakers, 2005).

Sway path

Sway path is a spatio-temporal parameter that measures total excursion of the COM in two planes (frontal and sagittal) over a defined period of time. Increased length sway path of the COM is a risk factor for falling in men (Campbell et al., 1989). Men also have greater postural sway path than women, although this difference mainly disappeared when height was adjusted for as a covariate (Era et al., 2006).

Sway range

Postural sway range (maximum excursions) can be measured in both the frontal plane (ML direction) and sagittal plane (AP direction). ML postural sway has been reported to be a closer indicator of poor balance than AP postural sway (Maki et al., 1994). Postural sway in both planes increases significantly (i.e. reduced balance) with increased age (Raymakers, 2005).

Postural stability measures and fall risk

Force platforms have been used to measure stability of postural control for a variety of reasons including:

- Differential diagnosis of clients with balance impairment
- Detection of clients at risk of falling
- Objective measurement of therapeutic efficacy of intervention
- Development of targeted interventions for an individual client
- To improve understanding of underlying pathophysiological conditions across a range of clinical presentations (Visser et al., 2008).

A variety of sway measures based on force platform assessments have been used in prospective studies to assess the accuracy of postural sway parameters to predict falls, and those that are relevant to community-dwelling populations are summarised in **Table 2-5**. Studies that include nursing home participants in the study population have not been included in this review, nor have studies that include moving platforms.

Table 2-5. Prospective studies using static force platform measures as predictors of falls

First Author, year	Sample size and age	Force Platform Measures used	Falls data collection method	Results
Bigelow (2011)	N=150, Age=82±8yr Independent living screened for balance rehabilitation or fall prevention interventions	ML and AP sway excursion, velocity RMS, sway area	Fall based on self-report over the last year	ML sway velocity differentiates single from multiple fallers with EC
Pajala (2008)	N=428, Age=69±3yr well screened active community-dwelling sample	ML and AP velocity and excursion EO, EC, dual task (tandem and side-by-side) velocity (degrees/sec)	47% single fall, 21% multiple fallers. Monthly calendar for 1 year	AP velocity significantly correlated to indoor falls
Boulgarides (2003)	N=99 Age=74±6yr Community-dwelling and independent – stand 5 minutes	EO and EC on firm surface and foam, mean velocity (degrees/sec)	42% fell, 18% multiple fallers. Calendar every 4 months for 1 year	EC firm surface predictive of falls
Bergland (2003)	N=307 Age=80 Community-dwelling and independent – able to stand 1 minute	EO, EC, dual task ML sway excursion	51% fell, 22% multiple fallers. Calendar and phone each 3 months for 1 year	ML sway excursion predictive of falls
Stel (2003)	N=524, Age=69-92yr Random community-dwelling sample	EO, EC and EO, EC tandem ML sway excursion	44% fell, 23% multiple fallers, Calendar and phone each 3 months for 1 year	ML sway associated with recurrent falls: OR=2.8; 95%CI 1.1 to 6.9
Brauer (2000)	N=100, Age=73 ±5yr Healthy community-dwelling with no fall 1/12	AP and ML COM excursion and velocity	35% fell, 16% multiple fallers. Monthly calendars.	No sway difference fallers/nonfallers Fallers delayed gluteus medius activation and slower stepping task

First Author, year	Sample size and age	Force Platform Measures used	Falls data collection method	Results
Hill (1999)	N=96, Age=74±4yr; well screened active community sample	ML COM excursion	49% fell, 23% multiple fallers. Monthly calendar and phone calls for 1 year.	No difference fallers/nonfallers
Maki (1994)	N=100, Age=83 independent ADL and stand unaided	Spontaneous sway path measured in mm	59% fell, 23% multiple fallers Postcards each week or phoned	Fallers had increased ML sway EC (P=0.004)
Topper (1993)	N=100, Age=83 independent ADL and stand unaided	RMS ML COM excursion	59% fell, 23% multiple fallers Postcards each week or phoned	Fallers had higher ML sway than non-fallers (P=0.0002)

ADL=Activities of Daily Living, AP=Anterior Posterior, COM=Centre of Mass, EO=Eyes Open, EC=Eyes Closed, ML=Medio Lateral, mm=millimetre, RMS=root mean square.

In summary, ML sway excursion appears to differentiate between those people who fall once and those people who are recurrent fallers, rather than non-fallers and those who fall once, especially when tested with the eyes closed. It may be that single fall episodes are most commonly a result of environmental or other features that do not necessarily reflect a lack of balance control, whereas multiple falls may be the result of significant changes within the postural control systems, and this may be indicated through increases in ML sway range. The context of inside and outside falls is interesting, with those falling inside being frailer, and perhaps falling with lower levels of perturbation. Centre of mass excursion has been found to be significantly related to indoor falls, but not outdoor falls (Pajala et al., 2008).

Searching patterns: the role of postural sway

It has been postulated (Mochizuki et al., 2006) that postural sway may form an important part of normal postural stabilisation by performing a search process. By spontaneously altering the position of the COM, information regarding changes in the position of the lower limbs is enhanced. If this is so then there are implications for using this measurement as an indication of poor balance.

At quiet rest there is usually a larger range of motion in the AP direction, compared to the ML direction (Mochizuki et al., 2006). This may be due to participants attempting to gain increased proprioceptive information from the ankle plantarflexors, by moving into dorsiflexion to stimulate the stretch receptors of the soleus and gastrocnemius muscles and to gain more sensory input from the soles of their feet. An increase in sway-range in the ML direction was seen when participants were subjected to conditions of real and perceived instability (Mochizuki et al., 2006). The increased sway seen with perceived instability provides evidence for central control of postural sway (Latash et al., 2003).

Balance measures using the force platform and foam insert

Useful additional information about sensory involvement and integrity in balance performance can be achieved by altering the amount and accuracy of sensory information available to the person being tested. For the somatosensory system, this can be achieved by testing static stance while on a foam insert compared to stance on a firm support surface. The use of a foam insert has been shown to be effective in identifying people with balance disorders (Shumway-Cook and Horak, 1986), however its use for discriminating balance performance between individuals with high functioning balance has not been established.

When visual input is reduced or eliminated, postural sway appears to be discriminatory between recurrent fallers and non-fallers, with recurrent fallers showing increased motion of the COM over the base of support (Lazaro et al., 2011). As well, age-related decrements in standing balance are seen when vision is removed and a foam cushion is used (Vereeck et al., 2008).

Chiang and Wu (1997) compared balance performance on foam to a firm surface, and measured short and long muscle latency time in an attempt to determine changes to the relative contribution of the different somatosensory inputs with the addition of the foam insert. Significant differences were found between the firm surface and foam for medium and long muscle latency times, but not in the short latency times. This was interpreted by the authors to indicate that joint and skin receptors are affected by the foam insert, but that muscle spindles within the gastrocnemius muscle are not so affected.

Overall, the use of a foam insert in measuring static balance may provide useful information regarding control of balance in a challenging situation, where somatosensory input is reduced. Using the foam increases the magnitude of all values recorded compared to tests of postural stability on a firm surface, making real changes, perhaps, harder to detect. Still, this may be a useful measurement in determining differences in performance for highly functioning community-dwelling individuals, and warrants further investigation.

The Romberg Quotient

The Romberg quotient is a measure of stability and relative contribution of vision and somatosensory input to static balance. It is defined by the equation:

Romberg Quotient=sway path with eyes open/sway path with eyes closed

The Romberg test usually indicates that postural stability is better with eyes open than eyes closed; the Romberg quotient (RQ) is approximately 2.5 in adults without neurological disturbances (Le and Kapoula, 2008).

Balance changes with aging

Older adults tend to make smaller and more frequent changes to their COM in stationary standing, compared to younger adults. In a comparison of postural control between older and younger adults, the older group were less prepared to move their COM towards the extreme of their base of support, inclining 36.1% less than the younger group in a forward lean position (Mackey and Robinovitch, 2006). It is suggested that changes to ML sway control in older adults who fall may be due to a decrease in the sensitivity of their postural control system in the ML direction (Melzer et al., 2010), with age-related dysfunction within the otoliths in the vestibular system being regarded as significant contributors to this (Serrador et al., 2009).

2.2.14 Sensation (somatosensory, vestibular and vision senses)

The brain receives information from three physiological systems (somatosensory, vestibular and visual) to use in the maintenance of balance. In healthy young people, limitations in one system can be compensated for by use of the other systems, but with aging, disease or injury, such compensations to balance maintenance in the presence of a challenge become less effective (Speechley, 2011).

Somatosensory

Peripheral sensation input from somatosensory receptors of touch, pressure and proprioception are important sources of information for the central nervous system. These provide the body with position sense information and allow it to be able to gauge an appropriate response to perturbations both at rest and in response to motion. Proprioception encompasses both directional movement sense and static joint position sense and is more difficult to test quantitatively than other peripheral sensation parameters (Petrella et al., 1997). Assessment of proprioception in standing provides more accuracy than in a non or limited weight bearing position, which is thought to be because activation of muscles in standing reduces the threshold required to activate proprioception receptors (intramuscular spindles). When standing a stimulus of only one-third that required when seated is required for perceived motion at the ankle (Refshauge and Fitzpatrick, 1995).

Peripheral sensation has been reported to be more important than the input from the special sensations of vision and vestibular input in the maintenance of postural stability in healthy adults (Lord and Ward, 1994). Impaired proprioception is associated with falls in older (mean age 74 years) community-dwelling women (Lord et al., 1994b). As well, adults who had a history of multiple falling or had recent fall-related fractures performed worse on measures of ankle tactile sensitivity that those with no fall history (Lord et al., 1994a).

Vestibular

Information is also received in the central nervous system from the balance receptors within the vestibular system - with the semi-circular canals stimulated by rotation of the head, and with the saccule and utricle providing information regarding the relative position of the head with respect to gravity. Input from these organs allows optic stability when motion is underway (Stelmach and Worringham, 1985). Sensory information is also supplied to the cerebellar nuclei in the archicerebellum, where balance and equilibrium responses are maintained (Crossman and Neary, 2005).

The postural role of the vestibular system includes reflexive orientation of the head to vertical, but not monitoring of body sway (Nashner, 1971). Measuring vestibular function is problematic, and procedures using a slow angular motion to test function did not find association between vestibular function and falls (Woolley et al., 1997). More recently studies using suppression of the vestibular-optic reflex as a measure of dysfunction within the vestibular system have found associations between poor performance and falls (Di Fabio et al., 2002) and fall-related fractures (Zur et al., 2006).

Vision senses

Visual acuity, contrast sensitivity and depth perception are well recognised as fall risk factors (Lord, 2006). Multiple fallers have been reported to have decreased vision, as indicated by all visual tests, with impaired depth perception (Nevitt et al., 1989), contrast sensitivity, and low-contrast visual acuity being the strongest risk factors (Lord and Dayhew, 2001). The use of multi-focal glasses is associated adversely with fall rates, with replacement of these with a single-lens set of glasses effective in reducing the number of all falls, outside falls and injurious falls (Haran et al., 2010). Dark adaptation is an important risk factor for night time falls (McMurdo and Gaskell, 1991). Interventions to reduce vision impairment can be beneficial with a recent review reporting that first eye cataract surgery reduced rate of falls (RaR 0.66, 95%CI 0.45 to 0.95) (Gillespie et al., 2009).

Sensory changes with aging

Central integration centres controlling balance rely on input from the peripheral somatosensory receptors of touch, pressure and proprioception, and the special senses of vision and vestibular input, with age-related changes evident within these three systems (Shaffer and Harrison, 2007).

A progressive decrease in sensory input from lower limbs is seen with aging (Calne, 1985). An increase in the latency of monosynaptic and multisynaptic connections with age has also been reported (Stelmach et al., 1989). Decreased spatial discrimination that is seen in aging may have some relation to changes in distribution of sensory receptors in the epidermis (Besne et al., 2002). Proprioception is one of the key sensations that the central nervous system uses to base current postural information on, and declines in lower-extremity vibration sense and proprioception are evident with aging (Shaffer and Harrison, 2007). Age related reductions in accuracy of both static position and passive range of movements in lower limbs have been reported (Skinner et al., 1984). This may be due in part to the higher threshold for proprioceptive stimulation that is found in older adults, especially in weight bearing positions (Bullock-Saxton et al., 2001). Older adults show greater reliance on the velocity feedback information to control upright postures than younger adults do (Davidson et al., 2011).

Structurally a decrease in axon population in the optic nerves is seen with aging (Johnson et al., 1987). Benjuya and colleagues (2004) found that vision was used preferentially to support balance in younger populations, with peripheral sensation being more important in the 65-84 year old cohort. Visual acuity is a parameter of vision that is affected with aging and used as part of a battery of tests to examine fall risk (Lord, 2004). Other visual measures, including contrast sensitivity and visual threshold to light were found in adults over the age of 60 to be significantly associated with falling (Klein et al., 1998).

A reduction in the number of a variety of vestibular structures including hair cells in semicircular canals, and in the macula of the saccule and uticule is observed with increased age (Stelmach et al., 1989). Neuronal loss within the vestibular nuclei is noted to be age dependent, and proposed to have implications for age related deterioration in balance (Tang et al., 2001). The implication of these structural alterations for changes in vestibular function is less clear, and the ability to directly measure changes in that system alone appears difficult. Recently vestibular testing, including the vestibular evoked myogenic potential, has been used to determine normal functioning of the saccule, and although standardisation of recording methods is still to be completed, there is some promising literature being developed (Walther et al., 2011). The ability to compensate for head motion by altering optic reflexes with input from the vestibular system deteriorates with age (Baloh et al., 1993), although the direct relationship to postural stability is unclear. Nevertheless a significant correlation between a decline in the vestibulo-ocular reflex function and balance measures suggest common factors may be responsible for concurrent declines (Kerber et al., 2006).

A close connection has been reported between sensory aging and aging seen in both the sensory-motor system and the cognitive system (Li and Lindenberger, 2002). Even considering the reduction in generalised sensory input with normal aging, (Stelmach and Worringham, 1985) decreases in balance (and increases in postural sway) seen with aging may be due to (or exacerbated by) a deterioration in central integrative processing. The lack of correlation between postural sway and specific sensory deficits supports the complexity of the integration of sensory input from a variety of resources. Benjuya and colleagues (.2004) found that changes in sensory input (reduction of vision or proprioception) resulted in older adults initiating a co-contraction strategy around the ankle.

Atrophy of motor cortical regions and the corpus callosum or degeneration of neurotransmitter production systems that occur with aging may singularly or together precipitate the decline in motor function, including balance, fine motor and higher cognitive deficits (Seidler et al., 2010). This is supported by the observation that older adults use more widespread cortical and sub-cortical areas for motor control than younger adults (Seidler et al., 2010).

In summary, age related changes to structural components within the nervous system individually and summarily result in increases in postural sway and decreases in balance control.

2.2.15 Reaction Time

Reaction time is defined in psychology as the time taken after the presentation of a stimulus, until the initiation of a response. Poor performance on simple reaction time tasks have been found to be a risk factor for falls in a variety of populations, including community-dwelling persons (Lord et al., 1994b). There is also a significant difference in reaction time for simple tasks between single and multiple fallers, with multiple fallers taking longer to respond (Maver et al., 2011). This difference is also true for more complex situations that depend on responses involving lower limb motor function where reaction time also includes choice decisions (Woolley et al., 1997). Reaction time does not correlate with body sway, when standing on a firm surface (Lord et al., 2007), but is moderately correlated when standing on a foam surface (Lord and Ward, 1994).

Reaction time changes with aging

Reaction time tasks that have been used in studies related to fall risk have been either simple reaction time tasks (requiring a simple motor response, e.g. task requiring pressing a button with a finger) or more complex tasks requiring choice as well (e.g. extending and flexing the knee). In community-based populations simple reaction time tasks (button pressing) are significantly different between older and younger adults, with a median increase of 26% reported across four decades starting in the twenties (Lord et al., 2007). The addition of a secondary cognitive challenge showed slowing of reaction time performance of a stepping task for older adults without change in younger adults, and this effect was more pronounced in those at risk of falling (St George et al., 2007).

Age related changes in reaction time may have several different causations, including changes to strength and central processing of sensory information. Mackey studied aging related changes to strength and speed of response within women and found a 27% increase in reaction time for the older group (66-90 years compared to 19-36 years) in a standing balance recovery task (Mackey and Robinovitch, 2006). The effect of this reaction time lag was exacerbated in those participants who demonstrated a slower rate of ankle torque generation (15.6%). As well as low strength, increased muscle co-contraction is another cause of reaction time lag seen in older adults (Bautmans et al., 2011).

Lower limb postural reactions also require central processing of proprioceptive input from the ankle muscles, particularly the soleus muscle (Taube et al., 2006). The central processing component of somato-sensory afferent input can take around 15ms, but this is dependent on the required force of contraction in response: high levels of force can reduce this time by up to 8 ms (Taube et al., 2006). Conduction time for the entire reflex, including a transcortical loop, could be as short as 86 ms (Taube et al., 2006). Impaired reaction time has been shown to increase the risk of injury after falling (Nevitt et al., 1991).

2.2.16 Physical activity as a fall risk

Physical activity has been described as any bodily movement (produced by skeletal muscles) that results in energy expenditure (Caspersen et al., 1985).

Low levels of physical activity and risk of falls

Evidence is growing to indicate that adequate levels of physical activity are important in maintaining physical function and mobility by impacting on both muscle strength and balance in older adults. An additional positive sequellae of this may be fall prevention (Gregg et al., 2000). Sedentary behaviour is associated with an increased OR of 1.14 (95%CI 1.10 to 1.82), with increased physical activity in daily life yielding significant reduction is falls that result in injuries (Thibaud et al., 2011). Inclusion of increased leisure time physical activity has been shown in a review of epidemiological studies to prevent hip fractures (Gregg et al., 2000). Lifelong moderate to heavy occupational physical activity is also strongly protective against hip fracture (OR = 0.53; 95%CI 0.30 to 0.95) (Jaglal et al., 1995). In a population with arthritis, participants with low levels of outdoor physical activity were found to have an increase in fall risk (OR 3.3; 95%CI 1.7 to 6.5) (Oswald et al., 2006).

In a review of population-based studies, increased physical activity was suggested as an effective strategy for adoption and inclusion in health promotion policy decision making (McClure et al., 2005). Physical activity guidelines for older people include participation in some form of physical activity each day (recommended 30 minutes moderate intensity) (Sims et al., 2010). Components that should be included are cardiovascular fitness, strength, balance and flexibility (Sims et al., 2010, Salem et al., 2009, Paterson et al., 2007).

High levels of physical activity and risk of falls

Improved function is associated with higher levels of physical activity, with benefits demonstrated for moderate to high levels of activity (Paterson and Warburton, 2010). This may be due to conditioning of muscles and their reflexive control.

Recently short term changes in static balance with physical activity and fatigue have been reported. A study of healthy and balance-impaired older adults (n=55, age=77 years) showed that both groups increased their ML sway range immediately after performing a 14 minute bout of physical activity, with implications for fatigue related increases in fall risks, especially in the balance impaired population (Egerton et al., 2009). In contrast, a later study investigating the effect of physical activity on dynamic balance by the same authors (Egerton et al., 2010) did not reach the same conclusions with improved co-ordination of muscle activity seen in a stepping task immediately after the same 14 minute physical activity protocol. This may suggest that the effect of activity on the control of static balance (ML sway) may be different to control of dynamic balance tasks.

Increased activity is associated with both an increase and a decrease in the rate of falling. The longer term effects of higher levels of physical activity appear to be protective, although there is increased risk of falling during an exercise bout. Increased exposure to fall risk is reported with increases in physical activity in men (Chan et al., 2007). Recurrent falls in active older adults have been associated with participating in sports (OR 1.56, 95%CI 1.07 to 2.28), high intensity activities (OR 1.75, 95%CI 1.09 to 3.16), and activities with a high mechanical load (OR = 1.70, 95%CI 1.01 to 2.83) (Peeters et al., 2010), however although these rates are high, injuries from these higher risk falls were not reported in that study. An increase in the variety of activities undertaken appears to be more important than the overall activity level, with protection against the number of falls and injuries from falls lessened with increasing numbers of activities participated in (O'Loughlin et al., 1993). It is plausible that the wider range of activities produces advantageous adaptation for balance control.

Overall, however, physical activity has a positive role to play in fall risk reduction in preventative and restorative contexts. It has a primary role in preventing the onset of pathology that can lead to increased fall risk and addressing age related decline in physical performance, a secondary role in slowing the progression of disease or impairments when pathology is present and a tertiary role in restoring function that has been lost due to pathology or disuse associated with that pathology (Rose, 2008).

Seasonal variation in activity

Both outdoor and indoor activity levels vary between summer and winter, and these variations are larger for older adults compared to their younger counterparts (Uitenbroek, 1993). Much seasonal research is performed in the northern hemisphere, with higher activity levels in summer measured by survey (Cheadle, 2006, Pivarnik et al., 2003), accelerometers and pedometers (Sumukadas et al., 2009, Buchowski et al., 2009) or both physical activity recall and accelerometer (Matthews et al., 2001).

Both duration and intensity of activity change with the season, with longer times and higher intensity in the summer months in the Northern Hemisphere (Sumukadas et al., 2009). There appears to be a gender difference, with men increasing their activity by 51 minutes per day, and 1.4 Metabolic Equivalent (MET) hours, compared to 16 minutes a day and 1.0 MET hour for women (Matthews et al., 2001). This seasonal mean difference of 1.2 MET hours for men and women combined is clinically important, as these results suggest that older adults only meet the ASCM recommended physical activity guidelines for older adults during spring and summer (Pivarnik et al., 2003).

Information regarding seasonal variation in southern hemisphere activity exists for younger females (Currie and Develin, 2002) and walking behaviours (Humpel et al., 2004) with cold and wet weather considered an important additional perceived barrier to physical activity (Salmon et al., 2003). The lower level of activity in the winter period in both hemispheres is attributed both to poorer weather and to shorter day light hours (Tucker and Gilliland, 2007). This has important ramifications for maintaining physical activity, for both the physical benefits of being active, but also for the potential to impact on vitamin D levels through access to sunlight, particularly Ultraviolet B (UVB) irradiation of the skin.

2.2.17 The role of vitamin D in fall risk

Vitamin D

Vitamin D exists in several forms, with the commonest being either D2 (ergocalciferol) or D3 (cholecalciferol). Vitamin D3 is ingested or produced through the action of UVB on 7-dehydrocholesterol in the skin (Annweiler et al., 2010). Approximately 90% of the vitamin D in the body is produced by exposure to UVB (Heaney, 2004). Cholecalciferol is converted to the 25-hydroxy derivative [25(OH)D] in the liver to provide circulating serum levels that are recognised to provide a functional indication of nutritional state (Heaney, 2004). The active form of vitamin D is calcitriol (1[25(OH)D]), produced in the renal tubules from [25(OH)D] (Pfeifer et al., 2009). This process is represented pictorially in **Figure 2-2**.

Serum levels of vitamin D

There is some difference of opinion as to the required levels of serum vitamin D for optimal health.

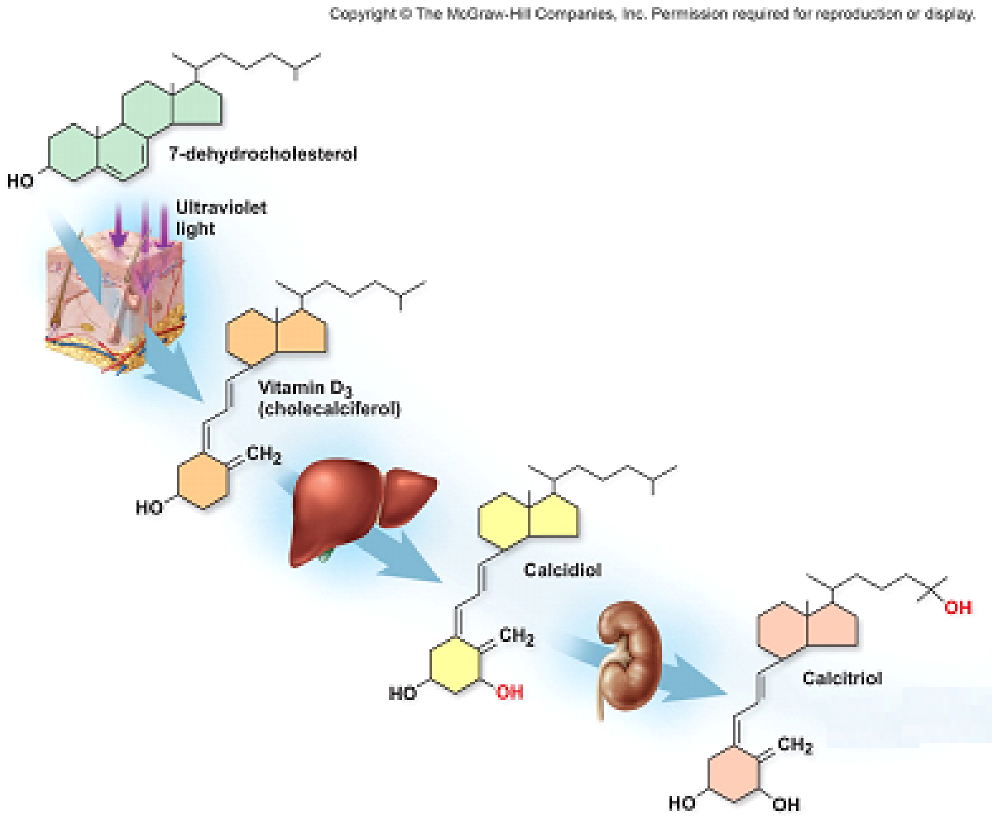

Figure 2-2. Cutaneous manufacture of (1[25(OH)D]) from exposure to UVB. Reproduced from Saladin, Anatomy and Physiology 6th Ed (with permission)

Vitamin D deficiency is considered to exist at serum levels of 25(OH)D < 25nmol/L, with insufficiency (as compared to overt deficiency) at levels between 25 and 50 nmol/L (Heaney, 2004). While levels above 50nmol/L were once considered optimal, levels between 75 and 110 nmol/L are now recommended for bone health (Bischoff-Ferrari et al., 2010) and levels of above 80nmol/L are required to maximise calcium absorption (Holick, 2004). Levels of toxicity exist at above 300nmol/L (Heaney, 2004).

Vitamin D and fall rate

Low serum levels of vitamin D are associated with an increased fall risk (Bischoff et al., 2003), with levels of above 60nmol/L associated with lower risk of falling

(Bischoff-Ferrari et al., 2009). The most recent meta-analysis of intervention studies that examine fall rates and vitamin D supplementation, reported improvements in fall rates in older adults of 14% (RR 0.86 95%CI 79-.93, I^2=7%) (Kalyani et al., 2010). The largest improvements were seen with supplementation of at least 800IU (Bischoff-Ferrari et al., 2004b) reducing fall risk by 60%. This generic assertion about the effect of supplementation on fall rates is not, however, supported in another meta-review, which reported that vitamin D supplementation in community-dwelling adults did not reduce falls universally (RaR 0.95, 95%CI 0.80 to 1.14; RR 0.96, 95%CI 0.92 to 1.01), but may do so in people with lower vitamin D levels (Gillespie et al., 2009). Proposed decreases in fall risk in participants with lower levels of serum vitamin D following supplementation may be mechanistically brought about through changes in balance control and muscle strength mechanisms. Differences in the health of studied populations, dose of supplementation, timing of reassessment and pre-existing levels of vitamin D all affect the outcomes in these studies. To be effective, it seems that dosage of supplementation needs to increase the serum of levels of vitamin D to at least 60nmol/L (Bischoff-Ferrari et al., 2009).

More recently a large RCT has provided conflicting information, showing an increase in fall rates in elderly participants randomised to vitamin D supplementation with the increased falls most apparent within the first 3 months after a high annual supplementation (Sanders et al., 2011). One explanation for this was that increases in muscle strength precede the ability to control the newfound mobility; thereby resulting in more falls and fractures (Annweiler and Beauchet, 2010).

Vitamin D and balance

Supplementation has been shown in several studies to improve postural balance in both community-dwelling (Pfeifer et al., 2000) and more frail older women (Bischoff-Ferrari et al., 2006). In addition improvements were also seen in performance of a dynamic balance task, similar to TUG, post supplementation (Bischoff-Ferrari et al., 2006), with concurrent improvement in fall rates. Improvements in both postural sway and TUG have been reported in a recent meta-analysis of supplementation levels over 800IU per day (Muir, 2011).

Vitamin D and muscle strength

The relationship between other physical performance factors, such as muscle strength, and Vitamin D remains unclear. Skeletal muscle cells have vitamin D receptors within their membrane. Vitamin D has a role in differentiation of satellite cells within muscle fibres as well as de novo protein synthesis within muscles in animal models (Buitrago et al., 2001) and lean muscle mass has been positively associated with levels of Vitamin D in healthy older adults (Scott et al., 2010).

Low levels of vitamin D produces myopathy at serum levels of below 25nmol/L, and longitudinal studies have shown associations between levels of vitamin D and muscle strength (Flicker et al., 2005). However a meta-analysis of 17 RCTs by Stockton (Stockton et al.) found no significant effect of vitamin D supplementation on grip strength (mean difference −0.02, 95%CI −0.15 to 0.11), or hip muscle strength (mean difference 0.1, 95%CI −0.01 to 0.22) when vitamin D deficiency was not present ([25(OH)D]>25nmol/L). Only one study has shown improvement in hip muscle strength with vitamin D intervention in institutionalised adults with vitamin D levels below 50nmol/L (Moreira-Pfrimer et al., 2009). A recently published meta-analysis (Muir, 2011) reviewing the effect of vitamin D supplementation has shown small positive effects on lower limb muscle strength (mean difference 0.05, P=0.04; 95%CI -0.11 to 0.20.) when supplementation is above 800IU per day.

At deficient levels of Vitamin D, the association between muscle strength and serum levels appears to be strongest, and it is possible that at more sufficient levels there may be a secondary factor that affects both. As the primary source of vitamin D is sunlight it may be that people who are more active outside will be both stronger and have higher levels of vitamin D. This is partially supported by a comparison of active people who had their activity classified as either indoor or outdoor, and that for similar levels of activity (i.e. the most active in this study) those whose activity was indoor had a 35% rate of vitamin D deficiency, compared to 11% for those who were active outside. This resulted in a mean difference of 16nmol/L for older adults, and remained true regardless of season (Scragg and Camargo, 2008). Large seasonal differences in vitamin D levels have been seen in younger men who spend a lot of time outside in the summer (49nmol/l) (Janet Barger-Lux and Heaney, 2002).

In summary, vitamin D supplementation appears to improve muscle strength only in people who have insufficient levels and when supplementation dose is adequate.

Vitamin D and aging

In older adults, the efficiency of cutaneous manufacture of vitamin D reduces with advancing age (Heaney, 2006). Cutaneous levels of the precursor for vitamin D production, 7-dehydrocholesterol, also fall as people age, further increasing the amount of UVB exposure required for manufacture of vitamin D (Holick, 2004).

Impact of season and latitude on Vitamin D

Season and latitude both affect levels of vitamin D, accounting for one fifth of the variation seen across a range of latitudes (van der mei et al., 2007). The seasonal variation is larger at the more extreme latitudes, due to the variation in ambient UVB available throughout the year (van der mei et al., 2007). In summer, UVB available to produce vitamin D is higher, concomitant with the hours of daylight. At the same time, the increased length of daylight also increases the ability to undertake outdoor activity, with a flow on effect that may improve strength or balance in daily life. This makes separating out the direct effect of seasonal changes on muscle strength, mediated by either vitamin D directly or changes in physical activity, difficult to determine.

Skin protection behaviours may also vary between seasons, but this area has been the subject of little research. Policy developed by the Cancer Council in Australia has been built around balancing the risk of skin cancer and the need for ultra-violet radiation to maintain adequate vitamin D levels (**Figure 2-3**). A RCT reported use of sunscreen to reduce the amount of the active form of vitamin D produced by about 10nmol/L over a summer period (Marks et al., 1995) compared to a placebo, although recent studies suggest that with usual application, the impact of sunscreen use is not sufficient to produce vitamin D insufficiency (Norval and Wulf, 2009).

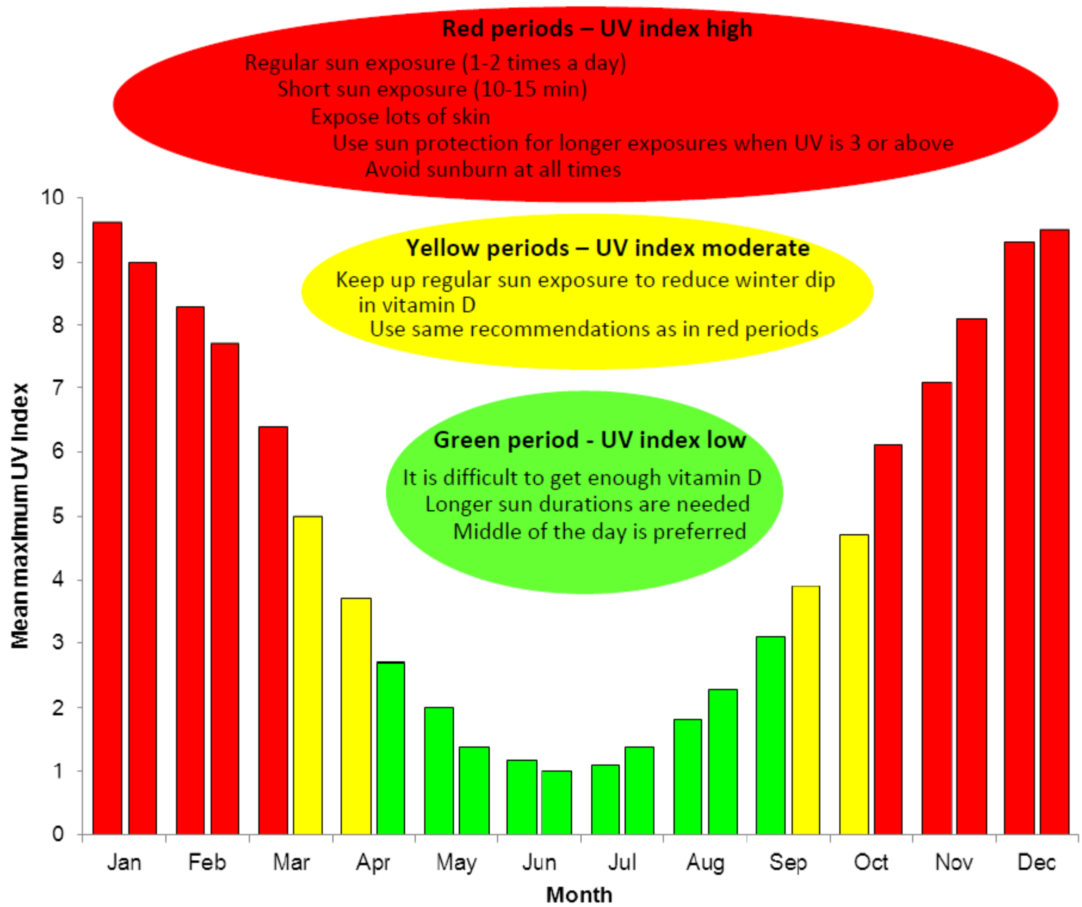

Figure 2-3. Balance between UVB exposure for vitamin D production and skin cancer risk in Tasmania, Australia.
Reproduced from Menzies Centre for Research

At 34 degrees of latitude in the Northern Hemisphere, there is enough ultraviolet for the skin to make Vitamin D all year around (Webb et al., 1988). At latitude 42 degrees, there is insufficient ambient ultraviolet for a period of three months during winter for manufacture of this substrate, whereas this window lasts 5 months at 52 degrees. Even though older adults have reduced capacity to cutaneously manufacture vitamin D, the relative contribution of sunlight exposure to produce serum levels of 25(OH)D appears more important than diet at all ages. Some seasonal variation in the relative importance of these two contributors to vitamin D status has been reported, with vitamin D levels during winter being affected by diet, however no such influence is seen in the summer months, when UVB from sunlight is more available (Pasco et al., 2001).

Diet and environmental contribution to vitamin D

Not many foods naturally contain vitamin D, and the usual diet provides only 100IU of Vitamin D, hence the importance of sunlight in the synthesis of this vitamin (Nowson and Margerison, 2002). As vitamin D is fat soluble, oily fish (like salmon and herrings) and non-fish liver are good sources of this vitamin. Mushrooms and yeasts will make large amounts of vitamin D when exposed to sunlight or UVB. Fortified dairy products and barley drinks assist dietary input.

Although dependent on skin type, amount of skin exposed and the amount of ambient ultraviolet available, the corresponding level that can be supplied from skin synthesis can be roughly calculated knowing that, '¼ of a minimal erythemal dose to ¼ of the body will produce 1000IU' (Dowdy et al., 2010). Frequent exposures to short bursts of UVB which do not allow sunburn are recommended to gain vitamin D without increasing skin cancer risks (Salman et al., 2008).

2.2.18 Fall risk factors for indoor and out-of-doors falls

Fall risk factors for inside and outside falls appear to be different (Bergland et al., 2003, Kelsey et al., 2010, Bath and Morgan, 1999). For example, even after adjusting for outdoor exposure, outdoor falls were independently predicted by vision impairment, symptoms of depression and a faster comfortable walking speed (Bergland et al., 2003). People who fell outdoors tended to be more active people with specific health issues, including an increase in the number of medications (Bath and Morgan, 1999). Higher amplitude of ML postural sway, a poorer score on the Timed Up and Go Test, and poor cognition were independent risk factors for indoor falls (Bergland et al., 2003). This may be due to increased frailty associated with indoor falls (Bath and Morgan, 1999).

2.2.19 Extrinsic factors

Extrinsic factors that contribute to falling include inadequate footwear (e.g. high heels, worn soles) (Koepsell et al., 2004), poor lighting (Kooijman and Cornelissen, 2005) and uneven or slippery surfaces (Menz et al., 2001) or going barefoot (Menz et al., 2006). External factors have been reported to contribute to between 16% (Decullier et al., 2010) and 31% (Rubenstein, 2006) of falls, although often in combination with intrinsic fall risk factors. Of note, older people perceive that external factors (such as uneven pavements and lack of handrails) are the most common causes of falling, and also perceive these to be modifiable (Braun, 1998).

Further discussion of external risk factors for falls is outside the scope of this literature review but is well covered in a recent review (Clemson et al., 2008).

2.2.20 Seasonal variation in fall rate and risk

The incidence of outside falls appears greater in winter, when the weather is colder (Luukinen et al., 1996), although the climate rather than the season may be more important in the number of falls. Despite this, increases in the proportion of falls that result in a fracture has been found to show variation that is seasonal, not weather dependent (Pasco et al., 2004). A southern hemisphere study of adults over 70 years found seasonal variations in falls amongst women but not men (Campbell et al., 1988). Hip fractures have been found to occur more frequently in winter, and are associated with the minutes of sunshine daily (Mirchandani et al., 2005) and seasonal osteopenia, related to variations in serum vitamin D levels, may be one influence to consider. Multivariate analysis indicates that up to 32% of hip fractures may be attributable to season, with this effect more pronounced in older (75+ years) aged persons (Mirchandani et al., 2005).

Seasonal variation in deaths in older adults resulting from accidental falls has also been documented, with higher death rates over winter in the United Kingdom (n=595) compared to summer (n=552) (**Table 2-6**).

Table 2-6. Seasonal variation in deaths from accidental falls in the United Kingdom 2005.

Falls	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Male	103	79	89	85	79	85	75	92	96	72	82	84
Female	128	109	113	85	90	96	96	88	71	99	93	92
Total	231	188	202	170	169	181	171	180	165	171	175	176

Reported as number of deaths from accidental falls,
(http://www.statistics.gov.uk/downloads/theme_health/Dh4_24_2001/DH4_24.pdf)

There are many factors that are important to consider for individuals at risk of falling. Some are modifiable, and some are not. Most accidental falls result from a combination of personal risk factors as well as interactions with the environment.

2.3 *Exercise and Physical Activity Interventions*

Physical activity is defined as 'any body movement that substantially increases energy expenditure' p.33 (Skelton, 2001). It includes both occupational activities and leisure activities. By contrast, exercise is described as a planned and structured activity that uses repetitive movements (Skelton, 2001) and is designed to improve or maintain specific components of fitness (for example strength, cardiovascular fitness, endurance or balance).

Exercise has the potential to affect many intrinsic fall risk factors. The ability of exercise interventions to impact on fall risk is determined by the type of program parameters included in the exercise design – including type of exercise, duration and intensity. Basal level of activity and other characteristics of particular populations also impact on the relative effectiveness of some interventions, depending on the physical needs of those groups. Variability in these factors, as well as the outcome measures used and variations in the health of the populations studied, makes comparison of intervention effectiveness difficult, but several meta-analyses to date have reviewed literature regarding effectiveness of exercises and physical activity interventions in addressing falling in older adults.

This section of the literature review examines the evidence in this area by reviewing the effect of different types of exercise and physical activity interventions on fall rate, and then describes the interventions that impact on the modifiable physical fall risk factors of lower limb muscle strength, static balance, dynamic balance and reaction time, with a focus on the impact of progressive resistance training.

2.3.1 Exercises to reduce fall rate

Although multifactorial assessment and multifactorial interventions are effective interventions to prevent falling (Chang et al., 2004, Gillespie et al., 2009), they are time consuming and resource intensive to perform. Exercise is the most researched single intervention for reducing falls across a range of populations and environmental contexts, and has shown positive effects on reducing falls rate and fall risk. Recently researchers in this field have collaboratively worked to develop a position paper for health professionals that incorporates evidence for defining recommended parameters of exercise program types for older adults (Tiedemann et al., 2011).

One of the early meta-analyses of RCTs that assessed the effect of exercise interventions on rates of falling and time to first fall, reported that fall risk for older adults is reduced for both generic exercise (IRR for falls 0.9, P=0.04) and also for exercise with a balance component (IRR=0.83, P=0.03) (Province et al., 1995). In 2004 Sherrington and colleagues reviewed the evidence in this area from six systematic reviews, including a Cochrane review, and was able to separate out good effects from individually prescribed physical activity interventions (which appeared to be of most benefit to frailer individuals) and some but less conclusive effects from untargeted physical activity interventions, particularly those that included a balance challenge component.

Sherrington and colleagues revisited this issue in 2008, and included a meta-analysis as well as a systematic review of 44 studies, and quantified the effect of exercise (generally) as reducing the rate of falling by 17% (2008). Further, exercises which challenged balance by reducing the BOS and controlling movement of the COM over that base produced improved outcomes, as did programs that included over 50 hours of exercise intervention. Interestingly the pooled effect of exercise in this meta-analysis, in terms of fall rate odds ratio, was the same as Province and colleagues (1995) found for exercise with a balance component 13 years previously (0.83) (Sherrington et al., 2008).

The most recent Cochrane review of falls prevention in the community setting by Gillespie and colleagues (2009) incorporated all relevant randomised trials published up to May 2008, across all interventions (including exercise) that report falls as one of their outcomes. One hundred and eleven trials were included, providing data from over fifty-five thousand community-dwelling older people. Of these studies, forty-three tested the effect of exercise on falls. From this review it was identified that both individual and group multi-component interventions were effective in reducing fall rate and the number of people falling. As well, evidence supporting single intervention and multi-component interventions was provided. Difference in effectiveness may be due to dosage of exercise. Tai Chi was also found to have a beneficial impact on fall rate. To date, no RCTs have investigated less common forms of exercise of a multifactorial nature, such as Pilates or yoga on falls incidence, and fall related outcomes.

Individual versus group interventions

The environmental context of the exercise delivery impacts on the success of programs, with individually prescribed programs in the home and exercising in supervised groups both found to be effective in reducing the rate of falling and the number of people falling, particularly when these programs included more than one type of exercise (Gillespie et al., 2009). Individually tailored exercise programs have been found to be particularly effective (Skelton et al., 2005), when designed to be carried out in the participant's home (Campbell et al., 1997, Robertson et al., 2001), especially when exercises were progressed according to participant's changing capabilities. Individualising a program requires some assessment of participants' abilities, and any individual asymmetry or individual problems relating to strength flexibility or balance noted. Many individualised programs include resistance, flexibility and balance training components (Skelton et al., 2005, Campbell et al., 1997, Campbell et al., 1999a, Robertson et al., 2002). An example of this is the Otago program, which has been the subject of a systematic review, analysing data from seven trials against control programs in healthy community-dwelling adults (mean age 81.6±3.9 yrs.) (Thomas et al., 2010). A reduction in fall rate (RR=0.68, 95%CI 0.56 to 0.79) and death from falls (RR=0.45, 95%CI 0.25 to 0.80) was found in a meta-analysis of data from those seven studies. Economic evaluation of the Otago program has shown that it is cost-effective, comparing the costs of the program to the hospital costs that had been averted (with cost savings of $NZ576 per fall prevented, and $NZ 1563 per injurious fall event prevented) (Robertson et al., 2001).

In summary, both individual programs and group situations have the capacity to allow for progression of exercises, and this has the potential to optimise fall related outcomes from different interventions.

Single component versus multi-component exercise interventions

Multi-component exercise programs include two or more of the following different components; strength, balance, flexibility or endurance training (Gillespie et al., 2009).

A common form of multi-component program involves the use of resistance training in combination with one or more other types of exercise including flexibility and balance, or functional training. These types of interventions have been observed to elicit positive effects on balance and fall rate (Carter et al., 2002, Day et al., 2002) or just balance (Hauer et al., 2001, Lin et al., 2007). Several programs reported improvement in fall rate without balance changes (Lord et al., 2003a, Means et al., 2005, Skelton et al., 2005), although balance was not measured in the most recent two studies. Some programs did not improve balance or fall rate, perhaps because of the high function population studied (Lord et al., 2005, Morgan et al., 2004), with the lower functioning participants reducing their fall rate, but the opposite occurring in the more highly functioning participants in the second study. The addition of an endurance or physical activity component to resistance training also had positive effects on fall rate (Campbell et al., 1999a, Robertson et al., 2001) balance (Ballard et al., 2004) or both falls rate and balance (Campbell, 1997, Barnett et al., 2003).

Howe et al (2007) reviewed 34 RCTs across a range of exercise interventions and, although supporting multi-component exercises, there is some evidence for single interventions of balance, resistance training, co-ordination exercises and walking in providing greater benefits than usual activity for older adults. Pooled data from these reviews provided evidence for improvements in dynamic balance measures with resistance training (e.g. Functional Reach P=0.021), or challenging static balance measures (e.g. single leg stand P=0.012), however other measures did not change (e.g. tandem stance P=0.42 or tilt-board P=0.25). These differences may be due to the type of intervention, with some resistance training programs including a level of challenge to the balance system, while others do not; or different dosages, and different populations. Resistance training, just targeting the quadriceps group, was not effective in reducing falls in older adults recently discharged from hospital (Latham et al., 2003).

As a single component intervention, balance-strategy training has been found to be effective in reducing fall rate (Nitz and Choy, 2004). Tai Chi as a single intervention (that includes balance, strength, coordination and flexibility elements) has been shown to reduce fall rate ((Li et al., 1995, Li et al., 2005, Wolf et al., 1996), and also found to increase time to first fall (Voukelatos et al., 2007). More recent research appears to reinforce the earlier identified benefits of reduced fall risk from Tai Chi practice (RaR 0.63, 95%CI 0.52 to 0.78; RR 0.65, 95%CI 0.51 to 0.82) (Gillespie et al., 2009).

Adherence

Adherence, both within the exercise program and then after completion of the program, has the ability to impact on fall outcomes. Various methods have been used to report adherence, for example postcards and home visits (Campbell et al., 2005), questionnaires (Jurkiewicz et al., 2011), as well as telephone monitoring (Shinji et al., 2007). Support from instructors is seen as valuable to the participant, especially in ensuring consistent information. High adherence to exercise after completion of the formal exercise program has been noted following some individualised exercise programs (Robertson et al., 2001). Campbell and colleagues (1999a) noted 44% of participants randomised to exercise were still performing the exercises one year after the program, with benefits at that time including both a reduction in fall incidents and time to injurious falls documented. These results were maintained at 2 years, with significantly higher activity levels compared to control participants recorded. Robertson (Robertson et al., 2001) repeated the program delivered by Campbell (above) with provision of the exercise program by a nurse (trained by a physiotherapist), rather than a physiotherapist, to 243 community-dwelling participants (mean age 81 years) with a similar rate of adherence at one year (43%) and similarly large and significant reductions in fall rate (46%; P=0.019) at one year.

Other studies have not had such a high adherence to exercise within the intervention, with low attendance being related to less understanding of the required exercise rate and intensity needed to produce benefits (Howze et al., 1989). Adherence appears to also depend on the relative importance that the participant places on the intervention(s) being suggested (Howze et al., 1989), as well as social support from family and friends (Tierney et al., 2011). Motivation has been linked to generalized feelings of well-being brought about by exercise programs (Kutner et al., 1997).

Duration

Exercise interventions involving durations as short as five weeks to programs performed several times a week for twelve months or more have been reported (Robertson et al., 2001). The combination of length of intervention period and frequency of the intervention results in a dosage that is independent of exercise intensity. The minimum intervention dosage reported is ten hours, with the other end of the intervention spectrum being three times a week for one hour for one year (150 hours) (Robertson et al., 2001, Shumway-Cook et al., 2007). Sherrington concludes in a meta-analysis that dosage of at least 50 hours is required to impact on fall rates (Sherrington et al., 2008).

Intensity

Rose (2008) suggests that intensity, as well as frequency and duration, is also important for the success of interventions to reduce fall rates. Several low intensity programs were not effective in producing improvements in fall rate, (Morgan et al., 2004, Reinsch et al., 1992) whereas higher intensity programs with staged levels of progression have had more effectiveness on this outcome parameter (Baker et al., 2007).

Sample populations

Interventions aiming to reduce falls have targeted a range of populations from healthy but sedentary to frail (Rose, 2008). Orr et al (2006) substantiates findings of improvements in both strength and balance in a ten week trial of dose specific strength training with the tenet that it was the weaker participants that had higher gains in strength. However, multiple fallers, whose problems may be more balance than strength related, responded less to exercise interventions (Sherrington et al., 2008).

Long term outcomes

The effects of fall intervention programs are not immediate, and need long term monitoring to determine real impacts. Follow up periods need to be of sufficient duration to maximise long term benefits. Relevant information about the pre-intervention fall rates also needs to be gathered in a way that allows comparison without memory bias. Prospective diaries before the commencement of the intervention appear an effective way to measure real change in fall rate, and remove recall bias (Skelton et al., 2005), although this is not often reported in the literature.

Changes in fall rate, following exercise interventions of more than six months, are common in the literature both immediately after the intervention (Thomas et al., 2010) and 12 months later (Liu-Ambrose et al., 2008, Robertson et al., 2001). More recently an innovative approach has been to prospectively measure fall rates, before the start of the intervention (36 weeks, Skelton et al., 2005). Although the gold standard of follow up time appears to be at least 12 months follow up (Thomas et al., 2010), some studies continue follow up for longer times with evidence of the long term benefits of interventions at both 18 months (Day et al., 2002) and 24 months (Campbell et al., 1999a).

2.3.1.8 Physical activity as a fall risk intervention

Increasing levels of physical activity appears to confer benefits to older adults who have only age-related physical fall risk factors (O'Loughlin et al., 1993), while other programs, especially those including a balance component, may be of more benefit to people with other physical fall risks (including poor balance and strength) (Sherrington et al., 2004). For community-dwelling older adults without medical impairments, promotion of increased levels of physical activity was effective in reducing rates of falling (Sherrington et al., 2004). Physical activity has an important role in preventing the onset of disability and reduced function, in older adults at lower risk for falling (Rose, 2008). A diversity of physical activities has been shown to be protective against falling (RR=0.6) (O'Loughlin et al., 1993).

2.3.2 Progressive resistance exercise – impact on fall risk factors: strength, balance and functional measures

Falls as an outcome measure is not often used in studies using PRT as a single intervention, but has been found to reduce falls when participants performed the intervention once or twice a week for one year (Davis et al., 2011).

Impact of progressive resistance training on muscle strength

The benefits of PRT programs to a variety of physiological and psychological parameters have been investigated widely over many years in older populations.

Intensity of PRT is important, with the largest improvements in muscle strength found when the resistance is high and muscles overloaded (Charette et al., 1991, Fiatarone et al., 1994). Changes to strength with PRT interventions are well supported in the literature, with a meta-analysis of knee extension strength in 15 samples of older adults showing improved strength outcomes (Dodd et al., 2004), but the flow on effect to balance changes was more variable.

Impact of resistance training on balance

A consensus within the literature as to the effect of resistance training on balance is yet to be achieved. Cross sectional studies have observed significant associations between balance and strength measures (84%, (Orr, 2010), however a 2010 review of resistance training interventional studies suggests that only 54% (27/50) of studies demonstrated significantly improved strength and balance measures (Orr, 2010). Results differ based on the populations within which the research is carried out, the duration and adherence to exercise as well as the intensity of the programs. Measurements of different aspects of balance (static, dynamic or functional) also allow authors to draw different conclusions about effectiveness of interventions; many studies measure more than one of these variables, with differing response across static, dynamic and functional balance making generalisations more difficult.

Several recent large systematic reviews have collated information to investigate the effect of PRT on balance (Orr, 2008) and on functional ability (including balance)(Liu and Latham, 2009) in older adults. The former review reports 29 RCTs, 16 of which were carried out in healthy community-dwelling populations. The second review analysed 104 trials comparing PRT with a control, which includes 28 that review balance. Of these 28, 16 measured balance in community-dwelling older adults, with no specific pathology and varying levels of basal activity (Liu and Latham, 2009). A list of randomised controlled studies focussing on PRT in community-dwelling older adults (of various abilities) that measured balance outcomes have been summarised in **Table 2-7.**

In summary, many of the studies included consisted of small samples (as low as 15, (Krebs et al., 1998)) with only five studies recruiting over 100 participants (Buchner et al., 1997b, Jette et al., 1999, Wolfson et al., 1996, Rooks et al., 1997, Orr et al., 2006). Although the duration of the studies varied from 8 to 26 weeks, most of the studies were over 12 weeks. The longest study with the most participants did not record any change in balance (Jette et al., 1999) but this may be due to the content of the program which was performed mainly in a seated position, with limited ability to affect standing balance. The use of different measuring tools for assessing balance affects conclusions drawn. The results from these studies, categorised by balance assessment type and tool, are summarised after **Table 2-7.**

Table 2-7. Effect of resistance training on static and dynamic balance in community-dwelling older adults

First Author, (year)	**Intervention type**	**Duration**	**Balance assessment used**	**Results**	**Rating of study Quality (PEDRO database)**
Granacher, (2009)	PRT with 2 groups PRT and control	13 weeks Machines	Functional reach Backward Tandem Walk	Improved 11% Improved 60%	2/10
Spennewyn, (2008)	PRT with 3 groups, 2x exercise and control	2xweek/16 weeks Machines – fixed or free-form plate	Unipedal stance on unstable surface	Balance improved 49% in fixed and 245% in free-form plates	Not in Database* 6/10
Henwood, (2008)	PRT with 3 groups PRT high velocity, PRT constant resistance and control	2xweek/24weeks Machines	Functional reach STS	Both PRT groups improved with high velocity training	4/10
Henwood, (2006)	PRT 3 groups PRT high and low velocity, combined PRT and function	2xweek/8 weeks Machines	Functional Reach	Improvement at high velocity training	5/10
Orr, (2006)	PRT 4 groups RT at 20%, 50% or 80% and control	2xweek/8-12 weeks Elastic Bands	Sway on moving platform and unipedal stance	Low load improves balance	6/10
Boshuizen, (2005)	PRT 3 groups High supervision, Low supervision and control	3x week/10 weeks Elastic bands	Static balance (seconds) in 3 different foot positions, TUG	Static balance Unchanged TUG Unchanged	4/10

First Author, year	Intervention type	Duration	Balance assessment used	Results	Rating of study Quality (PEDRO)
Liu-Ambrose, (2004)	PRT 3 groups PRT, agility and control (stretches)	2x week/25 weeks Machines	Postural Sway on foam	Improvements with PRT and agility	6/10
Sayers, (2003)	PRT 2 groups PRT slow and PRT high velocity (no control)	3x week/16 weeks Machines	Tandem walk forward and backward, stair climb, 10STS	PRT improves walk and stair climb with no differences with speed of exercise	4/10
Schlicht, (2001)	PRT 2 groups PRT and control	3xweek /8 weeks, Free weights	Single limb stance EC, 5 STS	1 leg stand Unchanged STS Unchanged	5/10
Westhoff, (2000)	PRT 2 groups PRT and control	3xweek / 12weeks Machines	TUG	Improvement TUG	5/10
Taaffe, (1999)	PRT 4 groups (including control)	1xweek/24weeks 2xweek/24weeks 3xweek/24weeks Machines	Backward tandem walk	Improvements not significant	5/10
Jette, (1999)	PRT 2 groups PRT and control	3xweek /26 weeks Elastic bands	Functional Reach, TUG, Single limb stance	Unchanged (Many exercises done in the seated position)	7/10
Buchner, (1997b)	PRT 3 groups PRT, aerobic and combination	3xweek/26weeks Machines	Walk on balance beam, tandem stand	Unchanged (balance task static and not challenging)	7/10

First Author, year	Intervention type	Duration	Balance assessment used	Results	Rating of study Quality (PEDRO)
Skelton, (1996)	PRT 2 groups PRT and control	1xsupervised and 2xHPweek/8weeks Elastic tubing and foam balls	Single Limb stance EO and EC Functional Reach	Improvement single limb stance 54% but not functional reach	4/10
Skelton, (1995)	PRT 2 groups PRT and control	3xweek/12 weeks Elastic tubing, free weights and body weight	Functional Reach, 10 STS	Unchanged	5/10
Topp, (1993)	PRT 2 groups PRT and control	3xweek/12 weeks Elastic tubing	Single limb stance EO and EC; backward walk	No difference from control	5/10

Abbreviations: PRT=Progressive Resistance Training, RCT=Randomised Control Trial, ILF=independent living facility, FLX=Flexibility Training, STS=Sit-to-Stand, TUG=Timed Up and Go, EC=Eyes Closed, EO=Eyes Open, mod=Moderately, CDA=community-dwelling adult; RMS=Root mean Square, COM=Centre of Mass, H=Home program.
Sourced from RCTs listed in (Orr, 2008)and (Liu and Latham, 2009) systematic reviews
*Not in PEDRO database – rating by candidate after training

2.3.3 Static balance

Timed single leg stance

Although measured quite frequently, single limb stance does not appear to change in most PRT studies, with no significant change compared to control groups seen in this parameter in community-dwelling older adults (Topp et al., 1993, Jette et al., 1999, Skelton and McLaughlin, 1996, Berg et al., 1997, Schlicht et al., 2001, Wolfson, 1996) A small number of studies have shown improvement in single stance time with eyes open but not eyes closed and these include a study which used stair climbing with a weighted belt as an intervention (Rooks et al., 1997). Another study also reports improvement in single limb stance, when measured on an unstable surface, and this extra challenge may make this test more sensitive to post-resistance training effects (Spennewyn, 2008).

Postural Sway

Static balance measures seem less sensitive than dynamic balance measures to the effects of PRT (Holviala et al., 2006), with no change seen in a low intensity intervention that used elastic bands in a frailer cohort (Boshuizen et al., 2005). One study that included a foam pad underfoot when testing postural sway found improvements with both eyes open and closed. The increase in the challenging nature of this test compared to static stance tasks on a firm surface may be a factor in this finding (Liu-Ambrose et al., 2004).

2.3.4 Dynamic balance

Functional Reach

Several RCTs investigating moderate to high intensity training using machines produced improvements in dynamic balance, as measured by Functional Reach (Ramsbottom et al., 2004, Sousa and Sampaio, 2005, Henwood and Taaffe, 2006). However some other studies did not (Skelton et al., 1995, Jette et al., 1999). The disparity in results may be due to small sample sizes and the fact that exercises in the Jette study (1999) were performed mainly in the seated position.

Backward walking

Lower intensity resistance training using elastic bands has been shown to improve time for the backwards tandem walk in community-dwelling adults (mean age 71years) (Topp et al., 1993). However these results were not replicated in highly functioning individuals (Taaffe et al., 1999).

Functional balance (Sit-to-Stand)

Timed Sit-to-Stand has been described as a good measure of functional ability and a predictor of falls, and is used often as an outcome measure (Lord et al., 2003b). Lui and Latham (2009) identified eleven RCTs that measured Sit-to-Stand performance, with significant improvement post training in the pooled data ($P<0.001$). In community-dwelling adults, improvements in Sit-to-Stand time was seen in most studies (Bean et al., 2004, Brandon et al., 2000, Kalapotharakos et al., 2005, Judge et al., 1994, Singh et al., 1997, Fahlman et al., 2007, Simons and Andel, 2006). In comparison, a single study (Schlicht et al., 2001) reported no difference in STS post training, however the sample size was quite small, with only 12 people in the exercising group.

Duration

Longer intervention times appear to have the greatest effect on balance, with improvements largest in studies with interventions exceeding 40 weeks. Despite this improvements are still evident for interventions between 14 and 26 weeks (Liu-Ambrose et al., 2004, Miszko et al., 2003), and even lower (under 12 weeks) (Nelson et al., 1994, Nichols et al., 1995, Sousa and Sampaio, 2005).

Summary – resistance training and balance

Overall, interventional studies showed significantly improved strength and balance in 54% of studies, with differences in outcomes accounted for by differing populations, dosage and type of interventions and the balance parameter measured (Orr, 2010). Static balance with the eyes open appears to not be affected by resistance training, especially in single leg stance. However the addition of dynamic conditions or a foam cushion to the measurement of postural sway does appear to have better sensitivity to identifying change in balance performance with PRT interventions. In healthy community-dwelling older adults, the variable of postural sway on a foam cushion may be more sensitive to exercise interventions than measuring postural sway without a foam cushion. Interventions of longer durations report larger effects. Dynamic and functional measures, such as Sit-to-Stand and Functional Reach that may rely on good lower limb strength for successful completion have generally reported positive outcomes from PRT. Frailer or weaker persons appear to gain more benefits, when the dose is sufficient.

2.3.5 Flexibility training, fall rate and balance

Of all the exercise interventions studied in older adults, the effects of flexibility training appear to be studied the least (Frankel et al., 2006). Nevertheless flexibility training is often incorporated with other exercises in a rehabilitative setting, for example with strength and cardiovascular exercise (Sherrington and Lord, 1997). However, regular stretching has not found improvements in range of joint motion, either in the short (less than one week) or longer term (greater than one week) (Katalanic et al, 2010).

Few studies compare flexibility training to PRT. Takeshima and colleagues (2007) compared five training interventions, including resistance and flexibility training, and found no improvements in strength or balance with the flexibility group, whereas both these parameters improved with the PRT intervention. This is in contrast to Barrett and Smerdely who found improvements in measures of dynamic balance (as measured by the Step Test) with a flexibility intervention (2002). Other studies have used flexibility training as a control intervention, in an attempt to ensure a control group receive similar social and physiological benefits of a group program (i.e. interaction with an exercise instructor, socialisation benefits of the group) without impacting on the physical outcomes of interest. However, depending on how flexibility exercises are administered, it is possible that they might actually impact upon physical outcomes such as strength and balance. This has important implications for those research studies which use flexibility as a control or sham intervention. The definition of what a 'flexibility training intervention' is, and what exercises should and should not be included needs clarifying by authors, as some exercises seen in community-based flexibility programs include balance tasks such as single leg activities.

Barrett and Smerdely (2002) found significant changes with both strength and flexibility interventions when testing dynamic balance using the Sit-to-Stand and the Step Test although improvements were greater after 10 weeks of strength training (performed 2x per week in a community setting) compared to the flexibility intervention within this study. The conclusion that the authors made that strength training produces better improvements than the flexibility program in measures of balance and gait ignores the significant changes seen with the flexibility intervention with the dynamic balance test of the Step Test (from 16.5 to 20.2 steps in 15 seconds).

Day and colleagues (2002) used a group exercise intervention that included flexibility as well as balance and leg strengthening over 15 weeks and found this the most potent of the three falls prevention interventions trialled (the other interventions were home hazard reduction and vision improvement). Improvements in balance were given as the reason for improvements in fall rate seen in the exercising cohort, because of the standing content of the program. Other mechanisms for improvement may include changes in flexibility, but because of the multi-component nature of this program that included balance, strength and flexibility training, it is not possible to tease out the individual benefits of each exercise type. Lack of dorsiflexion range at the ankle is associated with an increase in falling (Menz et al., 2005), so improvements in flexibility at this joint may positively affect fall rate or balance. Improvements in ankle flexibility and concurrent balance improvements (postural sway) have been found in a multi-faceted intervention with an exercise program that focussed on range of motion and strengthening exercises for the foot and ankle, together with orthoses and footwear interventions as required (Spink et al., 2011b). This intervention also reduced falls rate.

In summary, few studies have reported using flexibility training as an intervention and used falls rate or balance performance measures as outcomes. When it is included as part of a multi-component exercise program it is difficult to isolate the effect of the flexibility component, although some positive evidence exists when the ankle is targeted.

2.3.6 Other exercise approaches with potential impacts on balance and mobility - Yoga and dance, Tai Chi and Pilates

Yoga and dance

No RCTs for Yoga interventions measuring fall risk or rate were found on review of the literature. Low level evidence exists for improvements in balance with a 12-week bi-weekly Yoga intervention (Schmid et al., 2010).

Buchner included a dance-to-music aerobic arm into an RCT also comparing stationary cycling and walking, in a sample of 106 older adults with mild balance deficit, and found an 18% improvement in a balance task (distance walked on a narrow beam) (Buchner et al., 1997b). Improvements in single leg balance and Functional Reach were reported from a study with a similar dance-based aerobic intervention, that specifically targeted balance activities during the program (Shigematsu et al., 2002). More recently studies investigating the potential benefits to balance of dance-based games have not found the same improvements in balance in a highly-functioning group, who had not fallen within 6 months (Studenski et al., 2010). Overall, the potential of dance based activities to improve balance depends on the content of the activities, and type of population that it is being used with. Recently a computer interactive dance game (Dance Dance Revolution) was trialled with older adults (over 70 years of age) to determine optimal settings of this exercise video-game for maximising step rate, which may be useful to use in an intervention (Smith et al., 2011). Further research in this area is warranted.

Tai Chi

A Cochrane review of 11 articles published until 2001 determined a moderate impact of Tai Chi on balance (Komagata and Newton, 2003). More recently Tai Chi has been reported to lead to improvements in the Romberg Quotient (Lelard et al., 2010), and positively affect balance confidence (Rand et al., 2011). Sherrington et al describes the content of Tai Chi classes as being based in balance training (Sherrington et al., 2008), although there are both additional strength and flexibility components to this exercise approach. Tai Chi has various forms, some more challenging to balance than others, and this may be the reason for differences seen with intervention outcomes. Perhaps more importantly than changes to balance, Tai Chi has been reported in a meta-analysis, to improve fall rates (RR 0.65) as well as reducing the fall risk (RaR 0.63) (Gillespie et al., 2009).

Pilates

Pilates has become an increasingly popular exercise modality (Kaesler et al., 2007) which combines strength and flexibility training and, with the proposed benefits of improved abdominal muscle control, may provide an effective method of improving postural stability in a community-dwelling older population. Quality research into the benefits of Pilates is limited (Bernardo, 2007), with disparate measures and poor study design preventing definitive conclusions from being drawn from the literature. To date three published studies provide some preliminary evidence for the balance benefits of Pilates. Kaesler and colleagues (2007) reported improvements in postural sway and dynamic balance in an older adult population (66-71 years) after eight weeks of Pilates classes two times per week. However, their study was an uncontrolled study with a sample size of only seven completing the training. In a controlled study of 34 healthy younger adults (27.3 ± 3.6 years, 17 in each group), Johnson and colleagues (2007) reported a significant improvement in the Functional Reach test after five weeks of Pilates training that was not evident in the untrained control group, although no between group differences were evident. More recently a larger randomised controlled study (n=60) in older (>65years) nursing home residents found significant improvements ($P<0.05$) in dynamic force platform measures, muscle strength, reaction time, and fall rates compared to a control group after a 12 week Pilates intervention (Irez et al., 2011). However, whether these findings are able to be translated into a community-dwelling population is unclear.

While these studies indicate potential benefits from Pilates particularly in older adults, two interventions targeting younger populations did not report the same benefits (Kloubec, 2010, Caldwell et al., 2009). Of note, the Pilates program administered by Kloubec and colleagues (2010) did not include any standing exercises, which are potentially more likely to contribute to balance improvements than floor based Pilates activities. Furthermore, improving balance in an already highly functioning younger population may be more difficult and less relevant than improving balance in a higher risk older population.

In summary, this under-researched approach to multi-dimensional exercise appears to have potential benefits in balance and related physical performance in older adults, and warrants further research with more rigorously designed studies.

2.4 *Conclusion*

Accidental falls for older adults remain a major problem in Australia, and physical impairment is a major contributor to fall risk. Much of the exercise intervention research has also focussed on high fall risk groups. However, from a health promotion perspective, targeting of healthier, active older people might also have considerable potential to improve balance performance and fall risk in a preventive approach. This may be especially true for those adults who simply have age related declines in physical functioning. For older adults living in the community who are healthy but untrained and have no overt balance deficit, the benefits of different types of exercise intervention programs remain less clear.

3 GENERAL METHODS

3.1 *Overview*

This thesis comprises four studies, with a focus on physical fall risk factors: balance, strength and physical activity in older adults. This chapter reports the common methods used across several studies, while methodology specific to a single study (Study IV, Chapter 7) is included in that chapter of the thesis. The four studies are:

- Study I. Effects of resistance and flexibility exercise interventions on balance and related measures in older adults (Chapter 4)

This research explored the balance benefits to untrained older adults of participating in community-based resistance and flexibility programs in a randomised cross-over style design. Static and dynamic balance were measured, along with strength, activity and function.

- Study II. The long term benefits of a multi-component exercise intervention on balance and mobility outcomes in healthy older adults (Chapter 5).

This study evaluated the sustained benefits one year after completion of Study I. As well as reporting outcomes of muscle strength, balance and function, the study also investigated adherence to exercise and changes in exercise behaviour utilising a mixed methods analysis.

- Study III. Investigations into static and dynamic balance in older adults after training with Pilates (Chapter 6)

In a randomised cross-over style design, an exercise program based on Pilates principles designed to address balance, strength and flexibility needs of older adults was implemented and assessed. Strength, static and dynamic measures of balance, were measured, along with quality of life questionnaires completed.

- Study IV. Seasonal variation in Balance, Strength and Vitamin D (Chapters 7 and 8).

Over five seasons (incorporating retest of the original season) balance, strength, function and vitamin D were measured within a longitudinal study design, with no intervention by study researchers, to identify natural variations in these measures that occur over the seasons. Falls were recorded using a diary.

3.2 *Study Design*

3.2.1 Recruitment

Study I and II report outcomes for the same sample (shorter term outcomes in Study I, and longer term in Study II). The samples for Study III and IV were both separate samples to the sample for Studies I and II. Across all studies, men and women aged between 60 and 85 years were recruited through local media (newspaper and radio) and local community clubs. All participants were able to ambulate independently, and were living independently within the community. Participants were included if they were not currently suffering from, or had not recently suffered from, an acute medical condition, or an uncontrolled chronic condition. Participants were excluded if they had a history of stroke or other neurological disease, and were withdrawn from any of the studies if they suffered a medical condition during the study period that impacted on their ability to perform the balance or strength tests. A summary of the measures used in each of the studies is presented in **Table 3-1.**

Table 3-1. Summary of measures used in each study

Measures	Study I	Study II	Study III	Study IV
Force platform	ML sway range and velocity EO, EC, EO (foam) EC (foam)	ML sway range EO, EC, EO (foam) EC (foam)	ML sway range EO, EC, EO (foam) EC (foam)	ML sway range EO, EC, EO (foam) EC (foam)
Dynamic Balance	The Step Test	The Step Test	The Four Square Step Test	The Four Square Step Test
Functional Measures	Ten Times Sit to stand	Ten Times Sit to stand	Timed Up and Go	Timed Up and Go
Strength Measure	Cybex	Cybex	Spring Gauge	Spring Gauge
Activity Measure	PASE	PASE	CHAMPS	CHAMPS
Fall Record				Falls Diary
Serum Vitamin D				Blood sample
Readiness for exercise	PAR-Q	PAR-Q	PAR-Q	

EO=eyes open, EC=eyes closed, PASE=Physical Activity Scale for the Elderly, CHAMPS= Community Healthy Activities Model Program for Seniors, PAR-Q=Physical Activity Readiness Questionnaire, ML=Medio-lateral.

3.3 *Balance Measures*

Clinical and laboratory (force platform) measures of balance were used across all four studies. The measures were selected to provide a combination of reliable and responsive measures of both static and dynamic balance performance.

3.3.1 Force platform measures

An AMTI Accugait PJB 101, (Massachusetts, USA) force platform was used to measure static balance performance under four different sensory conditions. Force platform measures of ML sway range and sway velocity were recorded using either Netforce software (version 2.2; study I and II) or Balance Clinic software (version 1.4; study III and IV). Data was stored within these programs after being recorded.

For all the force platform tests the computer monitor was orientated so that the participants did not view the screen. The platform was set 15cm from a side wall so as to provide some protection from falling as required, but so that the participants would not be able to touch the wall without the assessor being aware. Stand-by assistance was provided by the researcher. The wall in front of the participants was blank and the distance set at three metres for consistency between testing.

The 500mm square platform was marked with tape in a T shape so that foot position was able to be repeated between testing sessions. Participants were instructed to place their toes behind the tape with their heels either side of the central bar of tape. The inside of the heels were 4 cm apart. All tests were conducted with shoes and socks removed. Each test lasted for 30 seconds and no practice attempts were given.

The four tests were:

- Test 1 (Eyes open)

Participants were asked to remain stationary with their arms by their sides and look straight ahead while standing on the force platform.

- Test 2 (Eyes closed)

The participants closed their eyes, while attempting to stand as steady as possible on the force platform.

- Test 3 (Eyes open, standing on foam)

Participants were asked to remain stationary with their arms by their sides and look straight ahead for the first test standing on an Airex foam pad (see below) on the force platform.

- Test 4 (Eyes closed, standing on foam)

The participants closed their eyes, while standing as steady as possible on the force platform and foam.

A 6.5cm high Airex pad (500 mm square) was used for the foam insert for the "standing on foam" test conditions (Airex Elite Balance-pad AG, Switzerland). The foam insert was marked in a similar pattern to the base platform so that foot position was again able to be consistently maintained. Tape on the platform and the cushion were in alignment so that foot position with and without the foam was similar, and reproducible with the inside of the heels 4cm apart. This is illustrated in **Figure 3-1**.

Figure 3-1. Foot Position for the force platform tests standing on foam

Fair to good test-retest reliability for computer-generated scores have been reported for force platform data in older community-dwelling adults, with the Intra Class Co-efficients (ICC) for the tests with eyes closed (0.710-0.946) and with eyes open (0.841-0.945) (Bauer et al., 2008). Reliability testing of static balance measures in our laboratory using the force platform utilised in all the studies presented in this thesis provided an ICC of 0.87 for retest reliability on the foam cushion with eyes open. There is some difference of opinion about the optimum length of data collection to maximise reliability and not induce fatigue in the participants. Greatest test re-test reliability was shown when recording data for between 20 and 30 seconds (r=0.86), compared to ten and 60 second recording times (Le Clair and Riach, 1996). However, recent review of 32 papers suggests that a longer time (90 seconds) or the averaging of three 30 second trials maximises test-retest reliability (Ruhe et al., 2010).

Improvements in postural sway have been found after interventions for older adults with functional balance training (Jarnlo and Johansson, 1991) and combined resistance and balance activities (Lord et al., 1995).

3.3.2 Clinical tests of standing balance

Clinical tests of balance are tests that can be performed quickly, with relatively little equipment, training required, or time of the assessor. For the studies in this thesis, several measures evaluating different aspects of standing balance were utilised. Normal footwear was worn.

Four Square Step Test

This test requires rapid stepping in multiple directions, and measures dynamic balance (Dite and Temple, 2002a, Dite and Temple, 2002b).

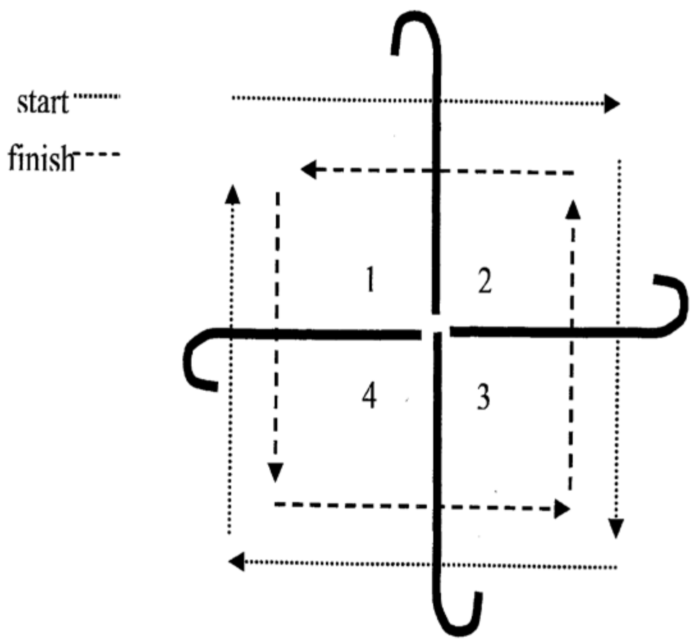

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Figure 3-2. Layout of walking sticks for the Four Square Step Test.
Sourced from Clinical Outcomes Measurements in Adult Neurological Physiotherapy

Using four walking sticks of 90cm length set at right angles, the participant stands in one of the four squares (square 1 – facing square 2) formed by the sticks, and when instructed to start, steps with both feet as quickly as possible into the square in front, to the right side, to the back, then to the left side (starting position), and then moves anti-clockwise back through all the squares to the starting position again (see **Figure 3-2**). The participant is instructed to complete the sequence as fast as possible without touching any of the sticks. Both feet must make contact with the floor in each square, while facing forward for the entire test. Timing starts when the first foot touches the floor in square 2, and finishes when the last foot touches the floor in square 1 (Dite and Temple, 2002b). One practice attempt was allowed before two trials were undertaken, and the fastest time recorded.

The Four Square Step Test has been shown to have both high inter-rater reliability (ICC=0.99) and retest reliability in older adults (ICC=0.98) (Dite and Temple, 2002a), as well as being sensitive to mild disturbances in balance function. This test has significant correlation with other tests used in this study series including the Step Test, Timed Up and Go test and Functional Reach (Dite and Temple, 2002a). Mean scores for older adults (mean 74 years) have been reported as 8.7 seconds (95% CI 7.4 to 10.0 seconds), and it has been applied and used successfully to discriminate between older adults who were single fallers, multiple fallers and non-fallers (Dite and Temple, 2002a). This measure has been responsive to change following both a resistance training and endurance training intervention in people with multiple sclerosis (Sabapathy et al., 2011), and balance training in frail older adults (Rugelj, 2010).

The Step Test

The Step Test, described by Hill et al (1996a), provides a clinical test of dynamic single limb stance balance that is appropriate for older adults with varying levels of balance deficits, including those with mild balance impairments. It is a test of rapid weight shift and stepping forwards and backwards on and off a 7.5cm block as quickly as possible. To perform the Step Test, the participant is asked to step their whole foot on a block 7.5cm high and 5cm in front of them, and return flat to the ground repeatedly over a 15 second interval. The number of steps completed in 15 seconds was recorded for each leg. The task was demonstrated as well as described, and the participant practiced before being timed. The instructions included not having to put the body weight on the step. The participant was asked to place their whole foot on the step and down again as fast as possible during the test, only making light contact with it. The results are presented as an average of the left and right legs.

The Step Test has a retest reliability ICC of greater than 0.90 in healthy older adults (Hill et al., 1996a). It has been shown to correlate well with other functional measures of dynamic balance, including Functional Reach, gait velocity and Four Square Step Test (Hill et al., 1996a, Dite and Temple, 2002a) and with force platform balance measures (Isles et al., 2004). Normative data for people over the age of 60, with a mean of 72.5 years, has been reported as an average of 18.2 steps in 15 seconds for left and right lower limbs (Hill et al., 1996a). This measure has been shown to be responsive to change in a circuit-style intervention for older adults with chronic stroke (Dean et al., 2000), and in healthy older adults (Yang et al., 2011).

Functional Reach

Functional Reach measures dynamic balance during a self-generated perturbation, relying on confidence to move the centre of mass to the limit of the base of the support anteriorly. The original study reporting the Functional Reach test measured COM excursion and reported moderate correlations with maximum arm excursion as part of the validation of the forward Functional Reach test, indicating that both tests reflect similar aspects of stability (Duncan et al., 1990). In study I and II of this thesis, participants were asked to lean forward as far as possible while standing on the AMTI platform, from a starting position with their arm held at shoulder height (90 degrees flexion), bending their trunk as well. Participants stood next to a wall in case stand-by assistance was required. This was repeated three times and the COM excursion in the AP direction was recorded on the force platform, instead of measuring the distance travelled by the outstretched hand. The three trials were averaged to obtain a result.

Inter-rater reliability ICC=0.98, and test-retest reliability ICC=0.92 is high in healthy people (Duncan et al., 1990). Norms for COM excursion during this functional reach have been presented originally in inches, with a mean of 3.47 in women and 4.28 in men, which corresponds to a metric measurement of 8.8 cm for female and 10.9 cm for male subjects (Duncan et al., 1990). It has been used frequently in assessment pre and post balance training programs (Skelton et al., 1995, Okumiya et al., 1996, Cress et al., 1999, Yang et al., 2011).

3.3.3 Measures of function reliant on lower limb strength and dynamic balance

These measures were performed with the participants wearing their usual footwear for consistency between data collection.

Ten times Sit-to-stand

Although used initially as a test of lower limb strength, the Sit-to-Stand test is influenced by factors that also affect balance and mobility, and as such is a functional measure of these two parameters (Lord et al., 2002). The Sit-to-Stand Test has also been related to postural control and falls in older adults (Whitney et al., 2005). The Ten Times Sit-to-Stand test was assessed using a 45 cm chair with no arms, and the participant was timed from when they started to move until when their back touched the chair again after completing ten full stands. One practice was allowed. The time was recorded in seconds with a stop watch, to within one tenth of a second. The upper extremities were not used to assist the motion.

Csuka and McCarty (1985) described the standardised test, with a co-efficient of variation of 6.8 per cent. Normative data for males and females of various ages without known pathology are provided in **Table 3-2**.

A resistance training intervention in older female adults improved Sit-to-Stand measures (Fahlman et al., 2011). Home based exercise for older women (82 years) showed improvement in this measurement over 4 months (Johnson et al., 2003).

Table 3-2. Normative data for the Ten Times Sit-to-Stand test by decade

Age (years)	**Women (mean in seconds)**	**Men (mean in seconds)**
60	17.6	16.6
70	18.4	17.6
80	19.3	18.5

Sourced from (Csuka and McCarty, 1985).

Timed Up and Go

The Timed Up and Go test is a measure of dynamic balance ability and mobility (including direction change). The participant was instructed on the command "go", to stand up from a 45cm chair without arms, walk three meters at their comfortable speed, turn and walk three metres back to the chair and to sit down again. Timing started at the instruction 'go' and finished when the participant sat down and their back touched the back of the chair. Each participant had one practice attempt before being measured.

This test has been shown to have high inter-rater reliability (ICC=0.98) in older adults in a community setting (Shumway-Cook et al., 2000), and high retest reliability, ICC=0.97 (Stefan et al., 2002). The Timed Up-and-Go test has been shown to identify fallers with 87% sensitivity (Shumway-Cook et al., 2000). Normative data for this test are described by decade by Steffen and colleagues (2002) and for the age ranges of participants recruited for studies described in this thesis are [mean (SD)] 60-69 years [7.8 seconds (2)] and for 70-79 years [9 seconds (2)]. A daily exercise program of balance and strength exercises and walking was shown to improve dynamic balance, particularly Timed Up and Go (Maejima et al., 2009). Positive outcomes for this variable have been reported following resistance training as well (Sousa and Sampaio, 2005, Westhoff et al., 2000)

3.4 *Selection of Measures of Strength*

Selection of strength testing parameters depends on the type of equipment available and the need or otherwise for portability of tests. Lower limb strength can be measured in a laboratory setting using an isokinetic dynamometer, whereas portable dynamometers have the advantages of being able to be taken to perform community testing, they are less expensive to acquire and quicker to perform testing procedures.

3.4.1 Cybex

In the laboratory setting, lower limb strength has been measured using a Cybex isokinetic dynamometer (Cybex 330; Lumex, Ronkokama, NY). It is useful and simple to administer, most commonly used to assess knee extension and flexion strength. Both of these muscle groups are important for normal gait (Lord et al., 1996) and standing up from a seated position (Lord et al., 2002). Maximum torque for right and left knee flexion and extension strength was measured in Newton metres at a rotational velocity of 60^{o} per second, after warm up trials for each of these groups were performed. Ten repetitions of 50% perceived maximal voluntary contraction were performed prior to a 30 second rest. Six repetitions followed, at 75% perceived maximal voluntary contraction, with a 1 minute rest afterwards. Three maximal efforts were recorded, with a standardised level of encouragement from the assessors. The peak torque attained during the three maximal efforts was used for concentric contraction for the hamstring and quadriceps muscle groups.

High ICC values (0.90-0.98) have been reported for peak torque for quadriceps and hamstrings being tested on the Cybex (Impellizzeri et al., 2008). The ICC of knee extension peak torque at 60 degrees/sec have been reported as 0.95 (Feiring et al., 1990). Peak torque measurements were found to have an absolute reliability of between 3·2% to 8·7% (Impellizzeri et al., 2008). Peak torque for the knee extensors at 60 degrees/sec were 137 Newton-meters in a study of women with a mean age of 36 years (Di Brezzo and Fort, 1987). Normative data for older men is presented by Murray in kg-cm for 50-65 years old (1,244±105) and 70-85 years old (953±75) (Murray et al., 1980). This piece of equipment, although precise and reliable (Impellizzeri et al., 2008), lacks the portability required in some testing situations.

3.4.2 Spring based gauges

Spring based gauges have the advantage of portability and the ability to measure muscle groups functionally relevant for balance control (e.g. quadriceps and dorsiflexors) in a cost effective manner. Their use as part of a battery of tests for fall risk is well documented (Lord et al., 2003b). Maximum isometric strength for the knee extensors was measured for left and right knees using a protocol described by Lord and colleagues (2003), using a strain gauge, raised chair and webbing system purchased from the Prince of Wales Medical Research Institute and set up as shown in **Figure 3-3**a. For testing, the participant sat on a high chair (seat 62 cm from the floor) with the hip and knee angles set at 90 degrees and the strap attached to the leg just proximal to the ankle, so that the line of pull from the bar at the posterior of the chair was horizontal. The participant was instructed to straighten their leg pushing into the strap as hard as possible. No practice trials were undertaken. Use of the arms to stabilize on the chair was not permitted. The participant performed three attempts at maximum extension of the knee, while sitting. The highest value maintained for 2-3 seconds was recorded (in kilograms). Each leg was tested separately and the highest value for left and right leg was averaged, to provide a single average quadriceps strength score for each participant.

This system has been reported to have a high retest reliability for knee extension (ICC=0.94) and correlated well with other portable measures of strength including hand-held dynamometers in a post hip fracture population (Sherrington and Lord, 2005). Using the spring gauge based system in a large trial of 278 people (age 72.4±7, 55% male) quadriceps strength was shown to be 35.8±12.5 kg (Callisaya et al., 2009).

Ankle strength was assessed using a similar spring based system attached to a foot plate (as in **Figure 3.3b**), using the same chair that was used for the knee strength testing in this protocol. The position of the foot plate was adjusted for people of differing leg lengths to ensure that ankle starting position was greater than 90 degrees to prevent active insufficiency producing aberrant results. The forefoot was anchored into the device and the participant instructed to pull the foot up into the strap. In a similar method to the knee extension protocol, 3 trials were performed and the highest value recorded. Each leg was tested separately and the highest value for left and right leg was averaged. Test-retest reliability for this ankle spring gauge system has been reported as ICC=0.88 (Lord et al., 2003b).

Figure 3-3. Position and equipment for testing (a) knee extension and (b) ankle dorsiflexion strength.

3.5 *Measures of activity*

Physical activity over a set period of time can be measured by questionnaire or by the use of a device designed to monitor and record activity (e.g. pedometer or accelerometer). This information is useful, both to determine uptake of physical activity during an exercise intervention, or to monitor the continuity of usual levels of activity during an intervention while under the control condition.

3.5.1 The Physical Activity Scale in the Elderly

The Physical Activity Scale in the Elderly (PASE) is a seven day recall tool that records hours of activity of differing intensity to attain a measure of energy expenditure in metabolic equivalent units (METS). The PASE is a scale for evaluating physical activity of older people and the resultant score is the sum of time spent in different activities across three domains: leisure, housework and occupation. The different activities are weighted for intensity to determine an overall score (in METS). Participants in study I and II completed this form at each test point with the assistance of a researcher. The questionnaire is attached in Appendix 1a.

The PASE has been validated by Washburn and colleagues as an age-appropriate recall tool for older adults to measure the volume of physical activity undertaken over a seven day period (1993). Test-retest reliability, assessed over a three to seven week interval was ICC=0.75 (95%CI 0.69 to 0.80) (Washburn et al., 1993), with similar reliability for mail administration (r =0.84). The PASE has moderate correlation with pedometer readings in a group of people aged over 70 years old (Washburn and Ficker, 1999) (r=0.64, $P<0.05$). In a study of healthy adults ages 65 to 100 years of age, normative values of 102.9 METs/week were recorded (Washburn, 1993). This test was not found to differentiate between healthy older females involved in differing levels of resistance training and a balance training intervention (Liu-Ambrose et al., 2010), but has been shown to demonstrate the effectiveness of class-based exercise programs for older adults with chronic health conditions (Reeder et al., 2008).

3.5.2 CHAMPS: Community Healthy Activities Model Program for Seniors

As part of a model of active aging, the Stanford Medical Research Institute developed an assessment tool to measure the level of participation in a variety of activities and provide an objective measure of overall activity (METs/week). This tool measures both frequency of particular activities and the amount of time spent in those activities over a typical week in the last month. The intensity of different activities is graded and the tool allows the estimation of metabolic units expended in hours/week. The questionnaire was administered by mail as part of a battery of tests, and they were checked at the visit by a researcher to ensure that all questions had been answered in a correct manner in an interview style approach. A copy of this questionnaire appears in Appendix 1b.

In a review that compared the CHAMPS to caloric expenditure in all activities, Stewart and colleagues found that the ICC for test-retest ranged between 0.58 and 0.68 in a cohort of active older adults (2001). These values remained stable over six months, and as such it is recommended as a tool to measure changes in activity participation with an intervention and consequently evaluate the effectiveness of those programs. CHAMPS has been used successfully to determine the effectiveness of a community-based intervention which were designed to increase physical activity in older adults (Laforest et al., 2009, Martinson et al., 2010).

In a review of measures of physical activity in older adults that included three activity questionnaires, CHAMPS was found to be the most consistent and have the least error of the questionnaires, although it consistently underestimated the physical activity levels of adults over 65 years (Colbert et al., 2011).

3.5.3 Readiness to participate in physical activity

The Physical Activity Readiness Questionnaire (PAR-Q) is a safe preliminary screening tool for proposed participants in an exercise intervention (Thomas et al., 1992). The PAR-Q was utilised as a screening tool as part of the eligibility selection process for those studies that had an intervention component. A copy of this questionnaire is included in Appendix 1c.

3.6 *General Assessment Procedure*

Participants attended the Exercise Physiology Clinic or the Exercise Physiology Laboratory at the University of Tasmania for testing for all studies conducted in Launceston. For the fourth study, additional sites in Hobart (The Menzies Research Centre) and Wynyard (James Muir Community Health Centre) were utilised as satellite research sites. All participants attended at a similar time of day for all testing points. For Studies I, II and IV, testing started at 8am and was finished by 11.30am on each day of testing. Two researchers worked concurrently on specific tasks so that each participant's testing lasted about one hour. Participants performed the balance tasks before the strength testing. Participants completed an activity questionnaire prior to or at each visit, and were interviewed re fall history, including fall incidence within the last 12 months at baseline. In study IV, fall diary completion was checked.

3.7 *Interventions*

Detailed descriptions of the interventions are included in the subsequent relevant chapters.

3.8 *Statistical analysis*

Statistical analyses were carried out using Stata (9-11) software (College, TX) to examine differences between the groups and changes over time, relevant to the particular study. Preliminary power testing was conducted prior to each study to determine sample size, and is reported in each chapter. Where manual entry of data was required, data was double entered to minimise error. All data was tested for normality of distribution (kurtosis, skewedness and heteroskedacity). Where data was normally distributed, repeated measures general linear modelling were used to determine differences between groups. Post-hoc testing using the Holms methods was used to correct for multiple comparisons when differences were found. When the data was not normally distributed, non-parametric measures were used (including log transformation of the data). Non-parametric tests were used for ordinal and categorical data. For study IV, two different types of analysis were used on the data: predictive equations based on the Edwards model (Pasco et al., 2004) were used to determine periodic variation in data; and mixed-model ANOVA to determine associations between variables of interest and the outcomes.

3.9 *Ethics*

Approval for all of the studies in this thesis was applied for from the Health and Medical Human Research Ethics Committee (Tasmania) Network and obtained. Written consent was provided by all participants. These studies complied with the

Declaration of Helsinki, and regular reporting has been undertaken. For studies I and II the approval reference number is H0007760. For study III the reference number is H0010572. For study IV the reference number is H0010561.

3.10 *Funding*

- Studies I and II were supported by funding from the Clifford Craig Medical Research Trust (B0014512) and the University of Tasmania.
- Study III was supported by the School of Human Life Sciences.
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Chapter 4 - Effects of resistance and flexibility exercise Interventions on balance and related measures in older adults.

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5 THE LONG TERM BENEFITS OF A MULTI-COMPONENT EXERCISE INTERVENTION TO BALANCE AND MOBILITY IN HEALTHY OLDER ADULTS

Preamble

This study describes data collected one year following the previous resistance and flexibility interventions evaluated in Chapter 4, and compares short term outcomes at the end of the interventions with 12 month outcomes. As well as physical measures, qualitative data regarding exercise behaviour post intervention as well as perceptions of program benefits were collected at 12 months. The candidate collected and analysed all of the physical data. Appointments were organised by Jodi Almond (Honours student). The candidate (Marie-Louise Bird) was responsible for preparing methodology for the follow up, manuscript preparation, with relevant input from co-authors as well as Kiran Ahuja and Iain Robertson (statistical advice). The data presented in this chapter has been published (Bird, ML and Hill, KD and Ball, MJ and Hetherington, S and Williams, AD, 'The long-term benefits of a multi-component exercise intervention to balance and mobility in healthy older adults', *Archives of Gerontology and Geriatrics: An International Journal Integrating Experimental, Clinical and Social Studies on Ageing*, 52 (2) pp. 211-216. ISSN 0167-4943 (2011).

5.1 *Background*

Physical and psychological benefits to older adults of participating in different types of exercise programs have been widely reported, however adherence to physical activity outside of formal programs is still poor (Rhodes et al., 1999). Physical activity participation rates for older adults (> 65 years) remain low, with only 16% meeting the recommendations of the American College of Sports Medicine Guidelines (Carter et al., 2002). In a large review of 5,537 adults over 65 years old, it was reported that 11% of older adults in the community participate in resistance training at a level to maintain strength (Pate et al., 1995, although for those who are considered active), this percentage rises to 24.7% (Kruger et al., 2004).

While supervised physical activity interventions have been successful in increasing physical activity in older adults over the duration of the exercise intervention, there is poor maintenance of exercise behaviors in the longer term (Rejeski and Mihalko, 2001). Without maintenance strategies in place, three out of four studies found no improvement in physical activity behaviour over the control at follow up at 12 months, and a general decline in physical activity behaviour between early and late follow up (6-24 months) (Müller-Riemenschneider et al., 2008).

A review of physical activity interventions for older adults outlines the lack of effectiveness, or lack of data to support effectiveness, at long term follow up (Van Der Bij et al., 2002). In a review of 29 studies King (1998) reports that 11 of these provide some form of data regarding follow up of periods from 3 months to 11.5 years, describing changes in physical activity or fitness parameters compared to controls. Only two of these report on fall risks, with decrease in fall risk at 18 months (Buchner et al., 1997a) and reduced risk of multiple falls at 8 months recorded (Wolf et al., 1996).

Howze et al. (1989) outlines the importance of the awareness of the participant to the benefits experienced by participating in exercise as one of three factors in an exercise behaviour modification index. Motivation to exercise has been linked to generalized feelings of well-being brought about by exercise programs (Kutner et al., 1997). Feedback from supervision enhances benefits in resistance training (Mazzetti et al., 2000).

The aim of this study was to identify long term changes in balance, strength, mobility and activity levels in a group who participated in a flexibility and resistance training program in a community gymnasium, compared to a control group. Secondary aims were to identify perceptions of improvements in function at 12 months, and for the exercise group, factors influencing ongoing exercise participation.

5.2 *Methods*

5.2.1 Participants

Forty-five inactive community-dwelling older adults participated in the original exercise study, with thirty-three returning for further testing one year after cessation of the exercise regime. Group allocation for data available at follow up is outlined in **Figure 5-1**.

5.2.1 Study Design

Following baseline testing consenting participants were randomised to either 16 weeks of resistance training followed by 16 weeks of flexibility training or vice versa.

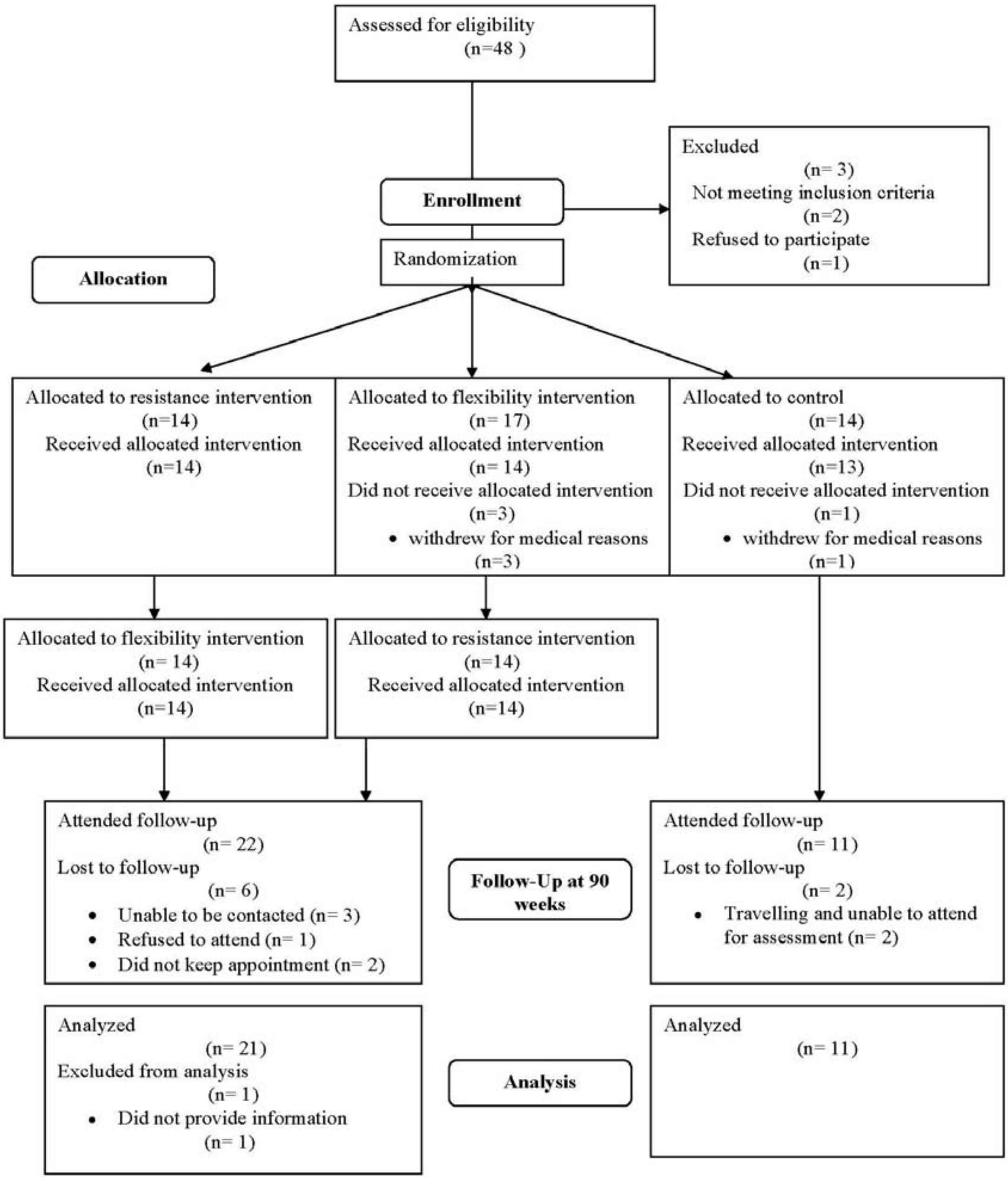

Figure 5-1. Group Allocation for study participants with compete data sets at time of follow up

A non-training control group was also established from the same population. Participants were requested to maintain their usual activity levels outside of the training intervention for the duration of the programs, and compliance to this request was measured with a Physical Activity Scale for the Elderly (PASE) questionnaire (Washburn et al., 1999). Ethical approval was given by the Health and Medical Human Research Ethics Committee (Tasmania) Network, and informed consent was gained by all participants.

All physical performance measures were undertaken at baseline, at the end of the first intervention (17 weeks), after four week washout (22 weeks) and following the second exercise intervention (39 weeks). Control participants underwent testing at baseline and 16 weeks. All available participants underwent the same series of tests again 12 months later (the focus of this paper). At the 12 month follow up, the participants were also interviewed by the researchers regarding ongoing activity and to gain their perceptions of the benefit of the program. Participants who were part of the exercise intervention who continued performing resistance training (ExC) have been separated from those who discontinued resistance training (ExD) in subsequent analysis of results. No participants identified that they were still performing flexibility classes.

5.2.2 Procedure and outcome measures

For the two groups participating in the cross-over design randomised trial (resistance training versus flexibility training), each exercise training intervention consisted of 3 sessions per week of either resistance or flexibility training. For two of the sessions per week participants attended a community gymnasium and the other session was home based. At the end of 16 weeks, after a wash out period (4 weeks), the participants performed the alternate exercise program.

The short-term effects of this intervention program (resistance and flexibility) have been reported previously (Chapter 4). For the purposes of this chapter, the two exercise groups (the group commencing with resistance training then doing a flexibility program; and the group starting with the flexibility program then doing a resistance training program) have been combined, and results are reported for the overall group of exercisers compared to the non-exercising control group.

All physical performance measures used in this study have been reported in greater detail in Chapter 3, and are summarized here. Balance and mobility were measured clinically by the functional tests of Ten Times Sit-to Stand (Csuka and McCarty, 1985), Timed Up and Go (Podsiadlo and Richardson, 1991) and the Step Test (Hill et al., 1996a). Force platform measures (Accugait PJB 101, Massachusetts, USA) of ML sway range and sway velocity were also recorded, using Netforce software (Version 2.2) under eyes open (EO) and eyes closed (EC) conditions, each for 30 seconds, with feet placed on a marked sheet (heels 4 cm apart) for consistency between assessment points.

Maximum torque for right and left knee flexion and extension was measured using a Cybex isokinetic dynamometer (Cybex 330; Lumex, Ronkokama, NY) and recorded as summed data. Participation in physical activity was measured using the PASE questionnaire described previously by Washburn et al (1999).

Perceptions of physical functioning were gained through the use of a survey tool at 12 months follow up, based on exit interview questions developed by Kutner et al (1997). In addition to answering the following questions, participants were asked to rate the relative magnitude of the perceived effects of the exercise program at the time of the 12 month re-assessment on a 200mm Likert scale (100 mm positive and 100 mm negative).

What effect has participation in the program had on your life?

How has being part of this program affected your sense of confidence?

How has participation in this program affected your activities of daily living?

How has being part of the study affected your regular physical activity levels?

What level of benefit do you feel you have gained from being part of this study?

5.2.3 Statistical analysis

Data were analyzed using STATA (version 10) software (Statacorp LP, College Station, Texas, USA). As reported previously, the data for the two exercise groups (resistance, and flexibility groups) were combined for the analyses in this chapter. Repeated measures ANOVA using general linear modeling was performed to compare within group rates of change over time between the two intervention groups (exercisers and controls). Post hoc testing using Holms test was used to identify within group changes over time and differences between the groups at baseline, the end of the intervention and at 12 month follow up. Results are reported as means or mean differences, with 95% Confidence Intervals (CI) and p-value. Balance, mobility and perceptions of physical functioning were compared between those of the exercising cohort ExC, (still exercising at 12 months), those of the exercising cohort ExD (had stopped exercising at 12 months) and the control groups using ANOVA (3 groups).

5.3 *Results*

5.3.1 Participant characteristics

Thirty-three participants were assessed at one year post completion of the study. Participant profile (mean; 95%CI) (age 67.1 years, 65.6-68.7), weight 77.9 kg (73.2-82.7), height 167.6 cm (164.6-170.6) and body mass index (BMI) 27.7 kgm^{-2} (26.0-29.4). This included 22 participants who completed both the resistance training and the flexibility protocol from the original study, and eleven control participants. Analysis of demographic data from baseline of the original study indicates that those participants who did not attend for follow up at one year were younger (1.8 years) ($P=0.0002$), had a lower BMI (2 kgm^{-2}) ($P<0.0001$) and were more active (19 points) ($P=0.0001$). Reasons for non-attendance at the 12 month re-assessment included inability to contact participants and participants being too busy to attend for testing (travelling). There was no significant difference between the exercising group and the control group in any of the measurements at baseline (**Table 5-1**).

5.3.2 Descriptive Statistics

Changes from baseline to the end of the 36 week study, and to one year later for the exercisers and the controls are reported in **Table 5-2**. Improvements in strength seen immediately post the exercise training ($P<0.05$) for the exercising group were not present at follow up, with no difference in strength seen between the exercise group and the control group.

Table 5-1. Baseline Characteristics of all participants

Variable	Exercisers Mean (95% CI) (n=22)	Control Mean (95% CI) (n=11)	P value
PASE	140 (117 to 164)	156 (120 to 190)	0.487
Strength (Nm)	385 (327to 443)	322 (193 to 451)	0.080
Sit to stand (s)	21.8 (19.5 to 24.1)	23.5 (19.6 to 27.5)	0.449
Timed Up and Go (s)	7.1 (6.6 to 7.7)	7.0 (6.0 to 8.5)	0.802
Step Test (steps/15s)	13.8 (12.4 to 15.1)	12.8 (10.8 to 14.8)	0.407
Sway velocity EO (cm)	103 (91 to 116)	113 (92 to 134)	0.413
Sway velocity EC (cm)	200 (178 to 223)	236 (144 to 289)	0.534
ML sway EO (cm)	3.8 (3.3 to 4.3)	3.9 (2.6 to 5.1)	0.880
ML sway EC (cm)	6.8 (5.9 to 7.6)	6.5 (5.0 to 8.1)	0.739

PASE=Physical Activity Scale in the Elderly, Nm=Newton Metres, s=seconds, cm=centimetres, ML=Medio-lateral

Table 5-2. Changes in clinical balance parameters between exercise intervention and control at one year follow up compared to baseline

Variable		Change exercisers Mean (95%CI)	Change control Mean (95%CI)	Value of mean difference	P value of difference
PASE	End of intervention	-5.3 (-21.2 to 10.6)	-13.9 (-41.7 to 14.0)	8.6 (-40.9 to 23.5)	0.601
	End one year follow up	-5.2 (-23.1 to 12.7)	-15.1 (-33.3 to 3.1)	9.9 (-35.4 to 15.6)	0.447
Strength (Nm)	End of intervention	34.5 (19.7 to 49.2)*	-1.8 (-21.6 to 18.1)	36.3 (61.0 to 11.5)	0.004
	End one year follow up	12.8 (-2.6 to 28.2)	11.4 (-10.3 to 33.0)	1.4 (-28.0 to 25.1)	0.917
Sit-to-Stand (s)	End of intervention	-5.4 (-7.5 to -3.2)*	-2.8 (-4.7 to -1.0)*	2.6 (0.2 to 5.4)	0.073
	End one year follow up	-5.9 (-8.2 to -3.7)*	-3.4 (-6.8 to 0.1)	2.6 (-1.5 to 6.7)	0.220
Timed Up and Go(s)	End of intervention	-1.1 (-1.7 to -0.5)*	0.03 (-0.6 to 0.6)	1.1 (0.28 to 2.0)	0.008
	End one year follow up	-1.1 (-1.7 to -0.4)*	0.3 (-0.7 to 1.3)	1.4 (0.2 to 2.5)	0.021
Step Test (steps/15s)	End of intervention	4.3 (3.1 to 5.4)*	2.6 (1.1 to 4.0)*	1.7 (-3.5 to 0.1)	0.063
	End one year follow up	4.1 (2.90 to 5.32)*	4.1 (1.92 to 6.41)*	0.1 (-2.5 to 2.6)	0.966
EC ML Sway range (cm)	End of intervention	-1.4 (-2.1 to-0.1)*	0.2 (-1.5 to 2.0)	1.4 (-.6 to 3.4)	0.180
	End one year follow up	-1.1 (-2.1 to -0.1)*	-1.4 (-3.6 to 0.9)	-0.3 (-2.7 to 2.2)	0.826
EO ML Sway range (cm)	End of intervention	-03 (-1.0 to 0.3)	-0.7 (-1.3 to –0.2)*	-0.3 (-1.1 to 0.5)	0.407
	End one year follow up	-0.5 (-1.1 to 0.9)	-0.6 (-1.3 to 0.1)	-0.1 (-1.1 to 0.8)	0.781

EC Sway Velocity (cm)	End of intervention	-31.8 (-51.8 to -11.9)*	-21.0 (-52.1 to 10.1)	-10.8 (-47.8 to 26.1)	0.565
	End one year follow up	-22.2 (-32.5 to -12.0)*	-20.5 (-46.9 to 5.9)	-13.6 (-48.1 to 20.9)	0.440
EO Sway Velocity (cm)	End of intervention	-23.3 (-37.0 to -14.6)*	-15.1 (-27.6 to -2.7)*	-10.7 (-27.5 to 6.0)	0.210
	End one year follow up	-22.2 (-32.5 to -12.0)*	-12.3 (-22.8 to-1.7)*	-10.0 (-24.7 to 4.8)	0.185

PASE=Physical Activity Scale in the Elderly, EO=Eyes Open, EC=Eyes Closed, ML=Medio-lateral,
*=significant difference compared to baseline at P<0.05, CI=Confidence Intervals

Significant improvements remained evident in the exercise group at one year follow up (P=0.001) for the functional task of Timed Up and Go. No improvements were seen with the control group at the end of the intervention period, and one year later the time to perform this task remained significantly longer than the exercise group (P=0.021). The improvements seen with the exercise intervention for the Sit-to-Stand task remained at one year (P<0.001), and no change was seen in the control group.

Improvements in sway velocity remained at one year follow up for both EO and EC conditions for the exercise group (P <0.05). There was no change seen in the control group at any time point under the EC condition; smaller but still significant improvements were seen in the control group when measured with the EO. The range of ML sway improved (decreased) in the exercise group under the conditions of EC at follow up (P=0.036; **Table 5-2**), but no significant change was recorded in the control group.

Interviews of the exercising cohort indicated that more than half (11 out of the 21 available for interview) were still undertaking a regular resistance training program (at least twice a week) one year after completion of the study intervention, with no comment from one participant. Nine participants were regularly attending a gymnasium and two participants were performing resistance training at their home with free weights. This subgroup of participants was further analyzed to determine differences in performance on the assessed tasks, and on perceptions of benefit from participating in the program, with the exercising group divided into those who had continued exercising (ExC) and those who had discontinued exercising (ExD).

Table 5-3 records participant perceptions of the impact of the program on five domains of benefit for the ExC, ExD and control groups. Significant differences between ExC and control groups were observed in the perceived value of participating in the program in all five domains. A significant difference was seen between the ExC and ExD groups in the participation in physical activity response only (P<0.01).

Table 5-3. Comparison of perception in benefit from participating in an exercise program between exercisers who have continued to perform progressive resistance exercises, those who have ceased progressive resistance exercise and control groups.

Perception	**Exercisers Mean (95%CI)**	**Exercisers (ceased) Mean (95%CI)**	**Control Mean (95%CI)**
Effect on Life	69.9 (58.3 to 81.5)	65.9 (41.0 to 90.7)	14.1 (-1.9 to 30.1)#
Sense of confidence	46.3 (33.1 to 59.6)	47.1 (15.1 to 78.)	7.7 (-8.0 to 23.5)#
Activities of Daily Living	50.3 (38.5 to 62.2)	31.6 (3.3 to 60.0)	19.1 (1.1 to 37.1)#
Participation in Physical Activity	54.9 (41.9 to 67.9)	15.9 (-4.0 to 36.9)*	19.8 (-6.8 to 46.3)^
Level of benefit	72.7 (59.5 to 85.9)	65.2 (39.0 to 91.8)	31.4 (-0.9 to 63.6)#

[#] Significant difference between both groups of exercisers and the control group (P<0.05)
*significant difference between exercisers (ceased) and exercisers (still going) (P<0.05)
^significant difference between exercisers (still going) and control group (P<0.05)

At the end point of the intervention (36 weeks after baseline) there were significant differences (P=0.004) in change in muscle strength from baseline between the ExC and ExD groups (mean difference 37.3 Nm, 95%CI 12.0 to 62.5). There was a significant difference in Step Test results at 12 month follow up (more than 3 steps/15 sec difference between the two groups, P=0.009) between the ExC and ExD participants. Trends were also evident between these groups in the other measures of balance and physical function (**Table 5-4**).

Table 5-4. Changes in balance and mobility parameters from baseline to one year follow up between exercisers who continued progressive resistance training and those who ceased

Variable	**Change Exercisers (continued) (n=11) Mean (95%CI)**	**Change Exercisers (ceased) (n=10) Mean (95%CI)**	**P value^**
Sit-to-Stand (s)	-7.04 (-10.68 to –3.4)*	-5.3 (-7.4 to –3.3)*	0.249
Timed Up and Go(s)	-1.40 (-2.28 to –0.52)*	-0.40 (-1.1 to 0.3)	0.112
Step (number)	5.2 (3.92 to 6.48)*	2.00 (-0.22 to 4.22)	0.009

*significantly different from baseline (P<0.005)
^P value for difference between the change in measures for participants who continued resistance training and those who ceased resistance training

5.4 *Discussion*

At one year after the cessation of formal activity within an exercise intervention, improvements persisted in some measures of balance and mobility for those in the initial intervention. More than 50% of the exerciser group continued resistance training regularly over the 12 months after completion of the formal intervention program. Those participants who continued to exercise had significantly greater strength gains during the intervention, and greater perceptions of the benefit of the program to their physical activity.

In addition to the observed physical benefits of the program in the short and longer term, the multi-component nature of the original intervention may also have had a positive impact on participant's fall risk (Gillespie et al., 2009), although the current study was not powered to identify changes in fall rates. Long term improvement in ML sway range in the exercise cohort has positive implications for fall risk, as older adults who exhibit increased sway ranges are more likely to fall, and to be multiple fallers (Maki, 1994). This may be related to ongoing exercise behaviors, as a reduction in fall rates for participants with high rates of adherence to an exercise program (measured at 12 month follow up) has been previously reported (Lord et al., 1995).

Maintenance of quicker times on both Sit-to-Stand and Timed Up and Go test demonstrates improvements to dynamic balance and mobility, both of which are important in fall prevention. Improved performance in the Step Test for those who continued with a program of progressive resistance training also reflects a higher level of dynamic balance control. These improvements may be due in part to the moderately high proportion of participants who have maintained a regular regime of progressive resistance exercise longer term. This is notable as our recruitment of participants included only people who were not involved in regular exercise programs prior to the study. Progressive resistance training leads to improvements in strength, which is especially valuable in this age group to address age related sarcopenia (Charette et al., 1991). Lower limb muscle strength has been identified as one of the most important contributors to the maintenance of stability and postural balance (Rubenstein, 2006).

The situational context of this program may have facilitated continued participation in resistance training. Many exercise programs that are the basis of research are situated in educational or research facilities. Our program varies from this, in having been located in a community gymnasium, which may have positive effects for continuity. However, the total amount of information on older adults relevant to the domain of participation based on situational contexts of physical activity remains small (King, 2001), although this is improving (Guili, 2012).

Support from a consistent group of peers may also have enhanced continuity, with seven out of the eleven exercisers still attending the same gym. Two others attended another gymnasium together, and two performed exercises at home after the formal exercise program ceased. While there is some variability in preferred options for exercise in the literature, one study reported that older adults expressed preferences for exercising with individuals of a similar age (rather than younger or older groups) (Beauchamp et al., 2007).

The supervision structure of the group exercise intervention allowed for individualization of progressive resistance training by a trained exercise professional. The positive feedback inherently delivered by improvements in actual weight lifted, as well as feedback given at regular reassessment points as part of this program, may both have positively impacted on ongoing participation in this type of exercise. The real gains in muscle strength may also have provided motivation to continue exercise. Our study supports the findings of Kutner et al (1997), who suggest that improvements in physical performance, and a change in perceptions, are both important for increasing an older person's adoption of increased levels of exercise after the cessation of a formal exercise program.

Limitations include our convenience sample selection. When analyzing the attributes of those exercisers who continued and those who did not continue progressive resistance training, the smaller numbers in each group limited our ability to detect significant differences between the groups. However, despite the small sample size, several significant between group differences were identified.

5.5 *Conclusions*

Long-term benefits to some measures of balance and mobility persisted one year after participation in a program that included resistance and flexibility exercise training. This community-based gymnasium and home program has resulted in moderately high levels of continued participation in progressive resistance training one year after cessation of formal exercise. Motivation to continue resistance training may be supported by real and perceived benefits in this form of physical activity.

6 A RANDOMISED CONTROLLED STUDY INVESTIGATING STATIC AND DYNAMIC BALANCE IN OLDER ADULTS AFTER TRAINING WITH PILATES

Preamble

The candidate (Marie-Louise Bird) was responsible for the study design, selection of balance and strength measures and selection of the activity questionnaire. Assistance with some data collection was received from summer scholarship students. James Fell assisted with data analysis and preparation of figures. The candidate prepared the initial manuscript and was responsible for journal publication selection and submission. The data presented in this chapter has been published previously (Bird, ML Hill, KD and Fell, JW, 'A Randomised Controlled Study Investigating Static and Dynamic Balance in Older Adults After Training With Pilates', *Archives of Physical Medicine and Rehabilitation* ISSN 0003-9993 93 (1) pp. 43-49 (2012).

6.1 *Background*

Reduced leg strength and poor balance have been identified as two factors that exercise programs have targeted and effectively addressed for the prevention of falls in an older population (Rubenstein, 2006). Multi-component exercise programs have effectively targeted strength and balance for the prevention of falls, with improvements in fall rates of up to 34% (Gillespie et al., 2009). Evidence also supports the benefits of balance training to all older adults, regardless of risk status (Sherrington et al., 2008). However, while a recent systematic review confirmed the beneficial role of exercise on balance in an older population, there was a degree of uncertainty as to the efficacy of some of the investigated exercise interventions due to a lack of standardised outcome measures to determine balance ability (Howe et al., 2007). Furthermore, whilst the evidence for health benefits derived from interventions that included training activities such as: gait, balance, coordination, and functional tasks; along with general physical activity, strength training, and multiple exercise types was good, the evidence from research which employed activities such as yoga and dance was less convincing.

Pilates has become a popular exercise modality which combines strength and flexibility training and, with the proposed benefits of improved muscular control of the deeper abdominal muscles (transversus abdominis, lumbar multifidus and the respiratory and pelvic diaphragms), may provide an effective method of improving postural stability in a community-dwelling older population. Pilates is used to describe any of the set exercises developed by Joseph Pilates. Quality research into the benefits of Pilates is limited (Bernardo, 2007), with disparate measures and poor study design preventing definitive conclusions from being drawn from the literature.

To date three studies have been published that provide some preliminary support regarding balance benefits from participating in Pilates. Kaesler and colleagues (2007) reported improvements in postural sway and dynamic balance in an older adult population (66-71 years) after eight weeks of Pilates classes two times per week. However, their study was an uncontrolled study with a sample size of only seven participants completing the training. In a controlled study of 34 healthy younger adults (27.3±3.6 years, 17 in each group), Johnson and colleagues (2007) reported a significant improvement in Functional Reach after five weeks of Pilates training that was not evident in the control group, although the group by time interaction was not significant and the effect of this improvement was only small (Cohen's d=.49). More recently a larger randomised controlled study (n=60) in older (>65years) nursing home residents found significant improvements ($P<0.05$) in dynamic force platform measures, muscle strength, reaction time, and fall rates compared to a control group after a 12 week Pilates intervention (Irez et al., 2011). However, whether these findings translate beyond the population targeted in their study was identified as a limitation by the authors.

Several studies have not identified any beneficial balance effects associated with Pilates programs. A recent study by Kloubec and colleagues (2010) did not find balance improvements in an active, middle-aged group (26-59 years) after a 12 week Pilates program, and this finding is similar to another study which investigated Pilates training in college-aged participants (Caldwell et al., 2009). However, improving balance in already highly functioning younger populations may be more difficult and less relevant than improving balance in a higher risk older population.

Consequently, the aim of this study was to conduct a randomised controlled trial to investigate the effects of a Pilates intervention on the variables of static and dynamic balance, and leg strength in a group of community-dwelling adults over 60 years of age.

6.2 *Methods*

6.2.1 Participants

Thirty-two independently living and ambulating adults over the age of 60 were recruited through local community groups in an urban area and via radio and print media. Participants were included if they were not currently suffering from, or had not recently suffered from, an acute medical condition. Volunteers who suffered from controlled chronic conditions such as arthritis or stable chronic cardiovascular or metabolic conditions (e.g. hypertension and diabetes mellitus) were included in the study. Ethical approval for this study was given by Health and Medical Human Research Ethics Committee (Tasmania) Network, and written informed consent was obtained from all participants prior to participation.

6.2.2 Study Design

A randomised, cross-over design (**Figure 6-1)** was utilised, which meant that all participants would receive the intervention (Pilates) during the study period. This approach was considered to increase likely recruitment of participants. Each participant was given a number at entry into the program, and then initially allocated to either the control or exercise group in a random order process (using a random number generator) by an independent researcher. Researchers involved in the testing of participants were blind to group allocation. Dependent variables were measured at four time points: baseline (T1), at an interim time point immediately after the first group intervention (T2), after a six week washout (before the second intervention period) (T3), and at the conclusion of the study after the second group intervention (T4). Each group completed five weeks of the Pilates (two group sessions per week) or control conditions.

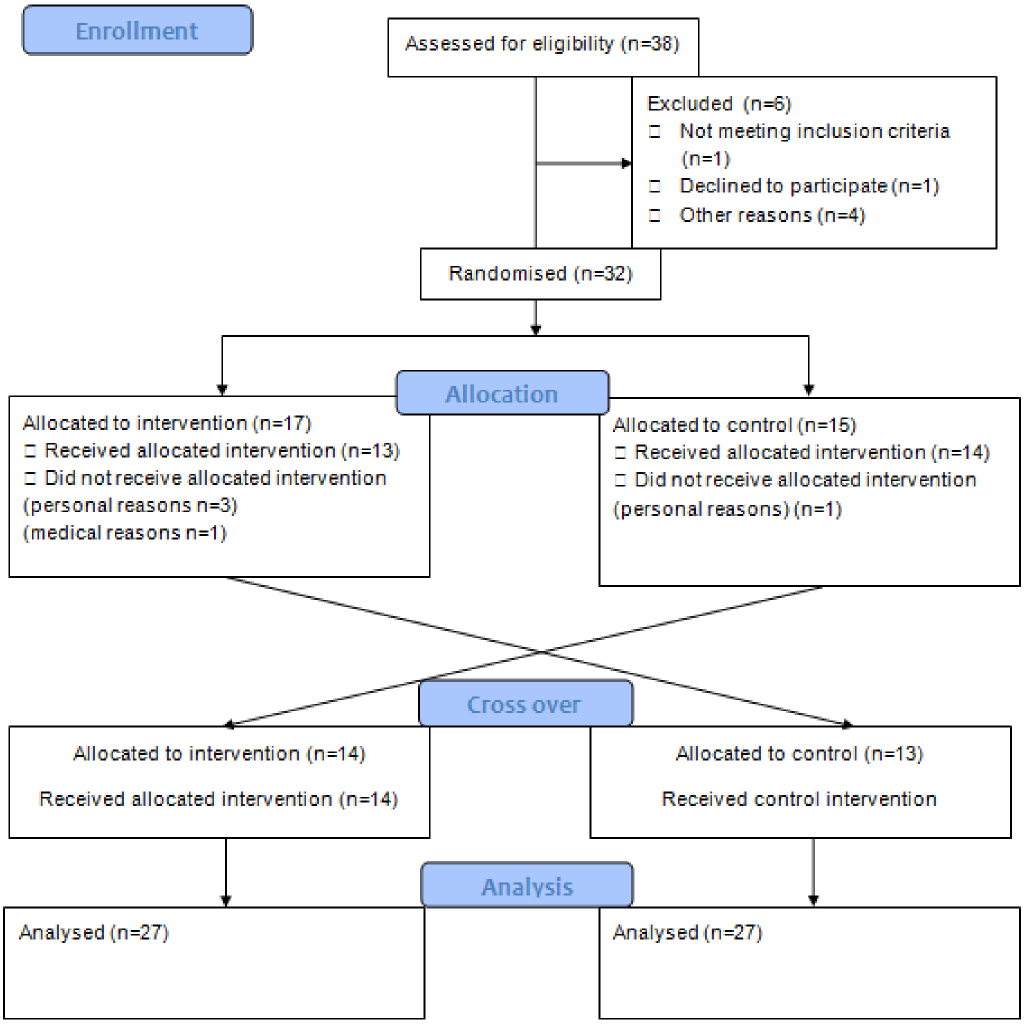

Figure 6-1. Consort flow diagram of design for Study III.

Participants under the control condition were requested to maintain normal physical activity, and this was monitored by use of the Community Healthy Activities Model Program for Seniors (CHAMPS) questionnaire (Stewart et al., 2001). Class attendance was monitored by the class leaders.

6.2.3 Procedure and outcome measures

An AMTI force platform (Accugait, PJB101 Massachusetts, USA) measured centre-of-pressure sway for 30 seconds under the conditions of eyes open and eyes closed, both standing on a firm surface and with the additional challenge of a medium density foam cushion (65mm Airex Elite Balance-pad AG, Switzerland). Sway data was analysed using Balance Clinic software (AMTI balance software, Accugait, Massachusetts, version 1.4) and ML sway range was recorded (in centimetres) as described in Chapter 3.

Dynamic balance was measured using the Four Square Step Test (FSST) and the Timed Up and Go (TUG) test. Strength for knee extensors and ankle dorsiflexors were measured for both legs using a spring based measurement system developed as part of a battery of fall risk assessment tests, the Physiological Profile Assessment (Lord et al., 2003b). Three attempts were performed on each side and the highest value for each leg recorded (in kilograms). More detail of all balance and strength test procedures, reliability and validity are included in Chapter 3.

6.2.4 Pilates Intervention

Classes were held in small groups of no more than six people. These classes were held twice a week and lasted for 60 minutes. Classes consisted of standing exercises and mat exercises followed by a circuit style session of Pilates reformer and mat based exercises (**Table 6-1**). A reformer is a spring-based piece of equipment that requires both concentric and eccentric muscle action to move a semi-stable platform. Focus included balance and lower limb strength, and the circuit style exercises were individualised to specific participant needs within the group structure.

Table 6-1. Description of exercise content for classes and home program.

Class program	**Class and home program**
Reformer: footwork	Standing Roll Down
Reformer: standing series	Arm arcs (performed in standing)
Reformer: scooter	Side leg series (performed in standing)
Trapeze: assisted squats	Bent knee fall out
Quadruped	Toe taps
(arm and leg extension using foam roller)	Side to side
	Quadruped
	Side kick
	Bridging

Small group sizes ensured that each participant performed the exercises with the best technique possible, and were progressed in terms of repetitions and load of exercises at the earliest opportunity. Participants were also given a copy of the mat exercises to complete on one other occasion per week at home with a diary (which included exercise description and graphics) to assist in compliance with this request. Classes were supervised by Pilates instructors who had undertaken training accreditation (Pilates Alliance)[1].

6.2.5 Statistical Analyses

Repeated measures ANOVA using general linear modeling was performed to compare between group changes with Pilates and usual activity (control) as the between group factor, and within group changes over time using STATA software (version 10.0, Statacorp LP, College Station, TX). Post hoc testing using Holms test

[1] http://www.pilatesalliance.net/

was used to identify within group changes over time. *A priori* power calculations were performed for the key dependent balance variable of Timed Up and Go, based on previous research (Bird et al., 2009, Kaesler et al., 2007) indicating that a sample size of 30 participants would be required to provide >80% power at an alpha level of $P<0.05$. We anticipated a 10% dropout rate, and therefore aimed for a starting population of 33. Clinically meaningful change was assessed by calculating the Cohen's d for effect size (ES) in relation to the changes that occurred during the Pilates intervention and during the control period. Data was analysed using an intention to treat model.

6.3 *Results*

6.3.1 Participant characteristics

Thirty-two of the 38 people who responded to media promotion about the project (mean age 67.2, SD=6.6 years; 27% men) were eligible for inclusion and 27 participants (mean age 67.3, SD=6.5 years: 22% men) completed the program. All participants were independently mobile and living independently within the community. No participant had any joint replacement or used any walking assistive device. Baseline physical activity, as measured by the CHAMPS questionnaire, was 61.2 (95%CI 46.5 to 76.0) MET hours per week. There was no change in CHAMPS score during the control condition ($P>0.05$). Five participants withdrew from the study after initial recruitment due to back pain (not associated with the program) (n=1), lack of time (n=2), and personal reasons (n=2) (**Figure 6-1**). There were no significant differences between those that withdrew and those that completed for any of the key dependent variables ($P>0.05$). All participants completed at least 80% of the Pilates sessions during the intervention periods.

Table 6-2. Comparison of change in each of the variables while undertaking the Pilates treatment period compared with change while undertaking the usual activity (control) period.

Variable	Pre Pilates	Mean difference from baseline	P	ES	Pre Control	Mean difference from baseline	P	ES	Difference between δ Pilates and δ control
	M (95%CI)	*M* (95%CI)			*M* (95%CI)	*M* (95%CI)			M (95%CI)
Timed Up and Go (s)	6.26	-0.41	<0.001	0.34	6.02	-0.14	0.119	NS	-0.2
	(5.97 to 6.72)	(-0.61 to -0.21)			(5.55 to 6.48)	(-0.46 to 0.18)			(-0.62 to 0.10)
Four Square Step Test (s)	7.86	-0.57	0.001	0.44	7.58	-0.34	0.107	NS	-0.23
	(7.30 to 8.42)	(-0.91 to -0.23)			(7.07 to 8.09)	(-0.76 to 0.07)			(-0.72 to 0.26)
Eyes Open (cm) ML Sway Range	1.96	-0.19	0.072	NS	1.81	-0.26	0.047	0.37	0.07
	(1.49 to 2.42)	(-0.40 to 0.02)			(1.57 to 2.05)	(-0.52 to -0.00)			(-0.4 to 0.39)
Eyes Closed (cm) ML Sway Range	2.18	-0.28	0.069	NS	2.24	-0.43	0.073	NS	0.15
	(1.72 to 2.64)	(-0.57 to 0.02)			(1.76 to 2.73)	(-0.89 to 0.04)			(-0.38 to 0.68)
Eyes Open on foam ML Sway Range (cm)	4.61	-0.78	0.001	0.46	4.61	-0.48	0.079	NS	-0.28
	(3.90 to 5.32)	(-1.22 to -0.34)			(3.98 to 5.24)	(-1.05 to 0.06)			(-1.11 to 0.54)
Eyes Closed on foam ML Sway Range (cm)	7.43	-1.64	<0.001	0.72	7.20	-1.08	0.054	NS	-0.56
	(6.62 to 8.30)	(-2.47 to -0.82)			(6.18 to 8.22)	(-2.17 to 0.02)			(-1.96 to 0.84)
Ankle Strength (Kg)	11.8	0.5	0.356	NS	11.6	0.2	0.715	NS	0.3
	(10.6 to 13.0)	(-.6 to 1.6)			(10.4 to 12.8)	(-.9 to 1.3)			(-0.9 to 1.5)
Knee Strength (Kg)	21.0	0.61	0.396	NS	21.9	-0.9	0.218	NS	1.6
	(18.8 to 23.2)	(-0.8 to 2.0)			(19.6 to 24.3)	(-2.5 to 0.6)			(-0.4 to 3.5)

CI=Confidence Intervals, ES=Effect Size, M=Mean, NS=Not Significant; δ=Change, ML=Medio-lateral.

6.3.2 Descriptive Statistics

There were no significant between group differences (Pilates vs. control) for any of the variables (**Table 6-2**). Over the entire duration of the study (T1-T4) there were significant improvements in all of the dependent static and dynamic balance variables ($P<0.001$) but not for lower limb strength (knee extensor strength $P=0.396$ and ankle dorsiflexor strength $P=0.356$).

During the first intervention period the Pilates training group experienced significant improvements in; TUG Test (0.90 seconds faster), FSST (0.95 seconds faster), ML sway on a foam cushion with the eyes open (0.66cm less) and with eyes closed (2.6 cm less), (all P values<0.016); with no significant improvement in the control group during this period (**Figure 6-2** and **Figure 6-3**). None of these parameters returned to baseline during the six week washout period (**Figure 6-2** and **Figure 6-3**). The pooled data at the completion of the study demonstrated there were significant changes pre- to post-Pilates training for most of the static and dynamic balance variables (**Table 6-2**), while for pre- to post-control condition there were no significant changes in any of the variables except for ML sway range with eyes open (firm surface) ($P=0.047$). The effect size of the significant changes are included in **Table 6-2**. The largest effect size was evident for the variable of ML sway range on the foam cushion with eyes closed for the Pilates condition ($d=0.72$), indicating a moderate effect size (Cohen, 1969).

Improvements in ML sway range on the foam cushion with eyes closed that occurred in the Pilates group during the first intervention period remained at the start of their control period (1.4 cm ($P=0.08$)). By contrast during this time the control group showed no significant improvement (P=0.284), despite decreasing by a mean of 1.1 cm. During the second group intervention period, between T3 and T4, both the control and intervention conditions responded to a similar degree, improving sway range by approximately 1 cm. (**Figure 6-2**).

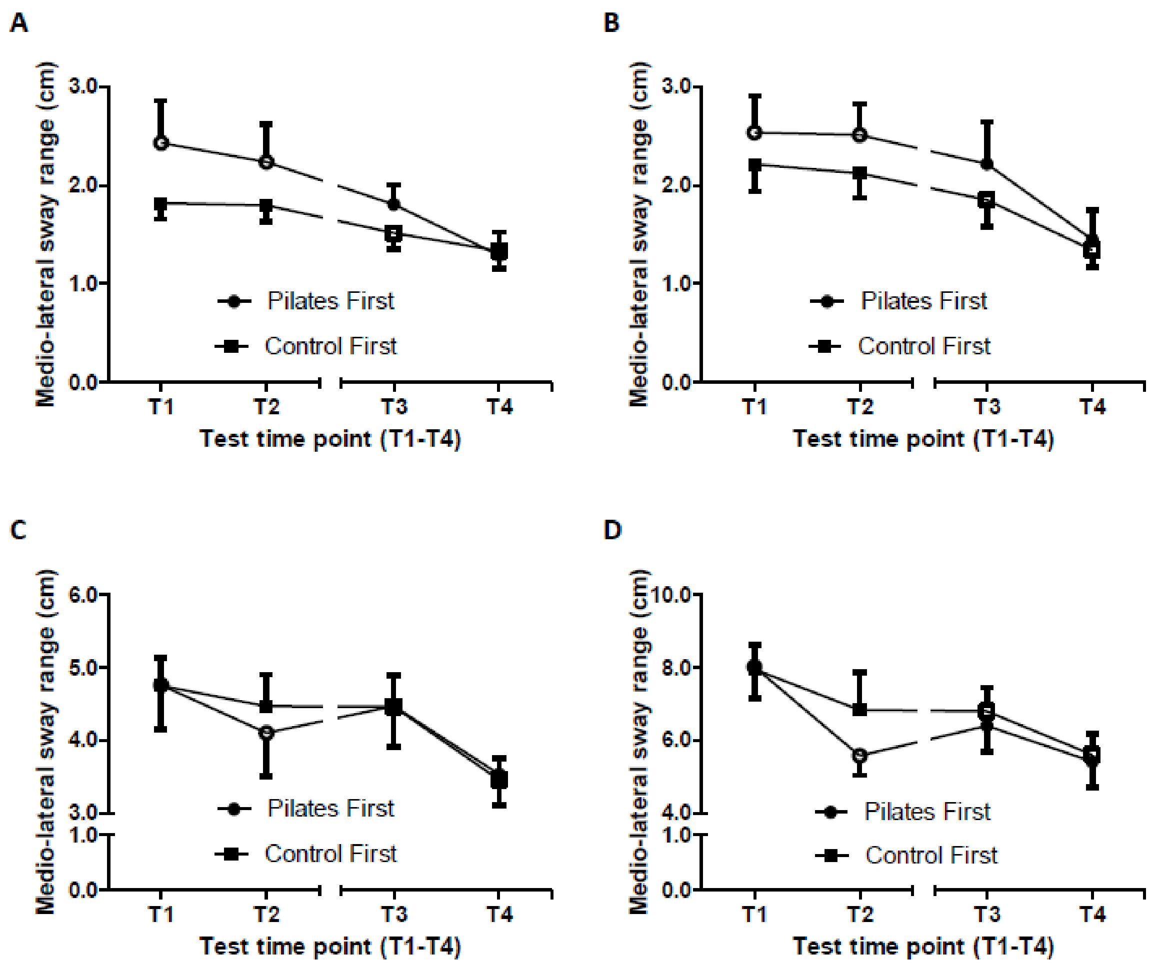

Figure 6-2. Force platform determined medio-lateral sway range (cm) with eyes open (A and C) and closed (B and D) and whilst standing on a 65mm foam cushion (C and D) over four time points (T1-T4) before and after either Pilates training or usual activity (control)

Both the dynamic balance measures of TUG Test and FSST demonstrated a similar pattern, with a significant improvement in the Pilates condition between T1 and T2, not evident for the control condition. Both groups then improved during the second intervention period (T3 to T4) although to a lesser extent (**Figure 6-3**).

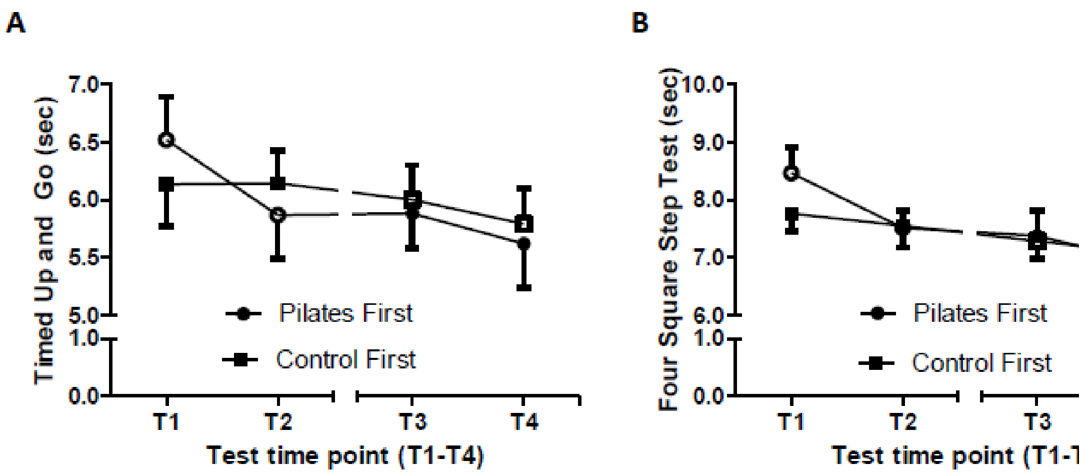

Figure 6-3. Timed Up and Go test (A) and Four Square Step Test (B) values (seconds) over four time points (T1-T4) before and after either Pilates training or usual activity (control).
Data presented as mean and standard error.

6.4 *Discussion*

This study has provided the first controlled evaluation of the effects of Pilates on the variables of static and dynamic balance in community-dwelling older (>60 years) adults. While the overall finding was that participation in Pilates did not lead to significantly greater improvements compared with the control condition of usual activity, this study adds to the existing literature regarding the potential benefits of Pilates exercise. Overall participants demonstrated a significant improvement in some of the key balance variables over the period of the study. Although these improvements could be suggestive of a learning response, the changes were generally largest while undertaking the Pilates intervention (**Table 6-2**). Factors that may have contributed to the overall improvement and the non-significant difference between the two conditions include the previously mentioned learning effect, the study design and seasonal influences.

The significant improvement in static and dynamic balance variables after Pilates training are in agreement with the findings of Irez et al (2011) and Kaesler et al (2007), the latter study reporting significant improvements of the same magnitude as our study in the vicinity of 27% for ML sway range with eyes closed on a foam pad (25% in current study) and 7% for TUG Test (also 7% in current study). During the current study the participants did not improve to the same extent during the control condition as during the Pilates training condition which, to some extent, discounts the possibility that seasonal changes or learning were solely responsible for any significant improvements.

Given that it was impossible to blind the participants to the treatment condition we cannot discount that a belief that Pilates training is of benefit could have contributed to some of the changes observed. Furthermore it is also possible that social interaction during classes may also have had a positive impact on outcomes. However, if these were contributing factors we would expect similar improvements across all of the measured variables. Instead only some of the measured variables significantly changed during participation in Pilates classes, with the largest effect evident for the balance platform variable of ML sway range on the foam cushion with eyes closed. Encouragingly, Kaesler and colleagues (2007) found a similar result with no significant improvements in their other static balance variables, only eyes closed on a foam cushion. It may be that balance on an unstable surface is highly dependent upon proprioception and muscle control, both of which respond favourably to Pilates exercise. Experience-dependent changes in motor control have been documented to occur within the central nervous system at multiple levels, from changes within synaptic connections to re-arrangement of cortical maps (Bolognini et al., 2009), although the measurement of this is beyond the scope of this study.

The moderate improvements in ML sway range, primarily when standing on the foam cushion with eyes closed, when visual and tactile cues are limited, infers that neural adaptations have occurred. The longevity of the functional implications of these adaptations is unclear and may have contributed to the improvement evident across the duration of the study. The improvements in balance measures at T2 for the participants in the initial Pilates intervention may have been maintained through to T4 due to resilience in learnt muscle recruitment strategies that did not disappear either during the washout or subsequent period when the participants continued to perform usual activity (total of 12 weeks). Improvements in functional balance have been found in a similar population with a Tai Chi intervention producing sustained improvement in balance measures, and decreased fall rates when re-assessed at six-month follow up (Li et al., 1995). Furthermore, a more recent study has attributed balance changes post Tai Chi training to improvements in the non-visual components of balance control (Lelard et al., 2010). Similarly, resistance training has been shown to produce strength improvements attributed to neural adaptations (Moritani and deVries, 1979) in a similar population, which were not completely lost after as much as 24 weeks of return to usual activity (Hakkinen et al., 2000).

The improvements in balance that we have attributed to neuromuscular adaptations initially occurred over a brief five week training period (approximately 15 Pilates sessions). This is the same time frame as a previously published Pilates controlled intervention (Johnson et al., 2007). While this is similar to the time taken to achieve changes in strength with resistance training (Abe et al., 2000), a recent meta-analysis of exercise interventions and falls prevention proposed that 50 hours was required to reduce the incidence of falls (Sherrington et al., 2008) Given that improvements in both ML sway and functional balance tests, such as the Four Square Step Test, have been associated with a reduced risk of falling (Barnett et al., 2003), from our study it appears that balance improvements may occur early in an exercise intervention while translation to a reduced incidence of falling takes longer. The changes for ML sway in this study are larger than that previously reported for resistance training or flexibility training alone in a similar aged cohort (Chapter 4) and this has implications for fall risks. Improvements in static and dynamic balance, although small, may also be clinically important. Consequently, the improvements in static and dynamic balance variables described in the present study may also have positive longer-term implications for decreasing physical fall-risk in this population, and this warrants further investigation.

Limitations

Long-term improvements in balance with Pilates in any population have not been reported previously in the literature, giving us little to base further recommendations for appropriate washout times for the cross-over study design. Thus, a cross-over study design may not be appropriate in an exercise intervention that aims to produce neuromuscular adaptation. The intervention was only of five weeks duration and it is possible that longer duration training may achieve greater effects. The small sample size of this study may have limited our ability to detect between group differences, and the information from this study may be useful for developing methodology for future studies.

6.5 *Conclusions*

Although there were no between condition differences between the Pilates and control condition, there were significant improvements observed in the pooled static and dynamic balance data from the two Pilates interventions. An absence of any difference between conditions may have been a result of the study design, as Pilates may influence neuromuscular adaptations with unknown resilience. The improvements in ML sway range and dynamic balance reported may have positive functional implications for physical fall-risk factors in an older population, although more research into this area is required.

7 SEASONAL VARIATION IN VITAMIN D STATUS, ANKLE STRENGTH AND ACTIVITY IN OLDER ADULTS: IMPLICATIONS FOR WINTER FALLS IN HIGHER LATITUDES

Preamble Chapter 7 and Chapter 8

The candidate (Marie-Louise Bird), together with supervisors and biostatistical advisors, designed the study that produced the next two chapters of this thesis. The chapters have been designed to separately examine strength and balance changes over the period of the study. The candidate gained funding for this project, prepared and submitted the ethics application and organised recruitment of participants. The candidate selected the balance, strength and activity measures. Assistance with a small proportion of data collection for the activity questionnaire was received from another co-researcher (Jeff Beckett). Blood collection and analysis was performed by another researcher (Jane Pittaway). This study received funding from the Clifford Craig Medical Research Institute and the Physiotherapy Research Fund (Beryl Haynes Trust). The data presented in this chapter has been accepted for publication (Bird, ML, Hill, KD, Robertson, IK, Ball, MJ, Pittaway, J. & Williams, A.D., 'Vitamin D status, ankle strength and activity show seasonal variation in older adults: relevance for winter falls in higher latitudes,' *Age and Aging* In press.)

7.1 *Background*

Serum vitamin D concentrations bear an inverse relationship to increased fracture rates from falls in older adults in the winter months (Pasco et al., 2004). While some of this effect is likely due to transient changes within the bone architecture, lower vitamin D levels also affect muscle sarcopenia in older adults (Scott et al., 2010) and hence risk of falls. During the winter season, people reduce their physical activity, particularly activity out of doors (Sumukadas et al., 2009) which may lead to further reductions in lower limb strength, although seasonal variation in muscle strength has not been investigated. Lower limb weakness has been found in a systemic review and meta-analysis to have an OR of 1.76 for a single fall and 3.06 for multiple falling, and is an important fall risk factor in older adults in a variety of environmental contexts (Moreland et al., 2004). Programs that include a substantial component of ankle strengthening appear to produce positive results in balance and fall risk (Hess and Woollacott, 2005, Amiridis et al., 2005).

It is important that people providing exercise interventions designed to reduce fall risk, or researchers who are drawing conclusions about the effectiveness of research interventions performed at various times of the year, are aware of any temporal variation in muscle strength, seasonal or otherwise. The present study was therefore designed to determine if lower limb muscle strength varies over the year, and if it does, to determine the relationship between muscle strength and the timing of changes in vitamin D status and levels of physical activity.

Vitamin D levels depend primarily on cutaneous manufacture of the 25 hydroxy form during direct exposure to Ultraviolet B radiation (UVB). At higher latitudes (i.e. further from the equator), sunlight hours during the winter months result in insufficient environmental UVB for the manufacture of vitamin D substrates (Webb et al, 1988), which can result in suboptimal or deficient vitamin D status. Vitamin D has a role in de novo protein synthesis (Buitrago et al, 2001), and severe vitamin D deficiency is known to produce myopathy at serum levels of <25nmol/L (Holick, 2007). However the relationship of insufficient/deficient levels of vitamin D (25-75nmol/L) on muscle strength is less clear (Rosen, 2011), particularly in older people living in the community. In a review of both longitudinal and intervention studies, the authors found inconsistent results for muscle strength changes in intervention studies providing supplementation with vitamin D (Annweiler et al., 2009). Differing results depended on the current level of the serum vitamin D status of participants, with benefits appearing to be isolated to participants with serum vitamin D levels of less than 25nmol/L (Stockton et al., 2011). Results also depend on the length of follow up, with changes in vitamin D being evident sooner and muscle strength changes taking longer to become evident (Pfeifer et al., 2009).

The amount of physical activity that older adults perform varies with the seasons, with an average for men over 60 years expending an additional 1.4 (95%CI 0.4 to 2.3) MET hours/day (an increase of approximately 35%) and 1.0 (95%CI 0.3 to 1.7) MET for women during summer compared to the winter season (Matthews et al., 2001). This holds true in older adults regardless of fitness status (Brandon et al., 2009) and appears to be associated with an increase in the number of different activities performed (Pivarnik et al., 2003).

A higher incidence of falling in winter has been related to lower air temperatures (Yeung et al., 2011), and the rate of fractures from injurious falls has been shown to increase at the end of the winter season (Pasco et al., 2004). More hip fractures occur in colder months, with ambient temperature associated most closely to injury, while prevailing levels of precipitation are less important, as many falls that result in fractures occur within the home (Mirchandani et al., 2005). Despite this, evidence exists for an increase in falls outside the house in winter (Luukinen et al., 1996). Risk factors for indoors and outdoors are different (O'Loughlin et al., 1994), and it may be that different populations (in terms of frailty) are also a factor to consider when reviewing fall venue. A higher proportion of winter fallers had lower limb weakness compared to fallers in summer and spring seasons (Yeung et al., 2011).

Recent population studies investigating the status of vitamin D have used large cohorts, measured at different times of the year (with each person only measured once) to estimate the population means at those times (Pasco et al., 2004, van der mei et al., 2007). In contrast, this study uses a longitudinal design to measure a variety of variables on each participant over five time points.

This chapter tests the hypothesis that higher muscle strength will be seen in summer and that this will be associated with higher levels of serum vitamin D, and higher activity and sun exposure levels.

7.2 *Methods*

7.2.1 Participants

Men and women aged between 60 and 85 years were recruited through local media (newspaper and radio) and local community clubs. All participants were living independently within the community and were able to ambulate independently. Participants were excluded if they were currently suffering from, or had recently suffered from, an acute medical condition, or an uncontrolled chronic condition; or were taking oral supplementation of vitamin D of greater than 800IU. Participants were also excluded if they had a history of stroke or other neurological disease, and were withdrawn if they suffered a medical condition during the study period that impacted on their ability to perform the strength tests. Kidney disease and liver disease both affect vitamin D metabolism, and any potential participants with either of these conditions were excluded.

7.2.2 Study Design

Over five seasons (incorporating retest of the original season) vitamin D status, strength and activity and hours spent outside were measured within a longitudinal study design, with no intervention by study researchers, to identify any natural variations that occur over the seasons. Data was collected from start of spring 2010 to the end of spring 2011. Data collection was timed to coincide with expected peaks and troughs in serum vitamin D levels (Pasco et al., 2004).

A-priori sample size calculation for a larger study based on ML sway range suggested a minimum requirement of 81 completed participants (minimum effect size 2.5 mm sway; SD 8mm; power 0.8, alpha 0.05): 98 were recruited with the anticipation of a 15% drop-out rate. *Post hoc* analysis suggested that this number might allow the detection of a minimum change in ankle strength of 8% and in activity of 20%.

7.2.3 Procedure and outcome measures

Lower limb muscle strength

Maximum isometric strength for the knee extensors (quadriceps) was measured for left and right knees using a protocol described by Lord (2003), using a spring gauge, chair and webbing system purchased from the Prince of Wales Medical Research Institute. The strength testing protocol was described in detail in Chapter 3.4. The values for left and right legs were averaged for use in the analysis.

Ankle strength was measured using a similar spring based system attached to a foot plate. The position of the foot plate was adjusted for people of differing leg lengths to ensure that the ankle starting position was greater than 90 degrees to prevent active insufficiency producing aberrant results. In a similar method to that used for quadriceps strength, three trials were performed and the highest value recorded. Right and left leg values were averaged for use in the analysis.

Vitamin D

At each time point venous blood samples were collected following an overnight fast of at least 10 hours. Whole blood samples were allowed to clot at room temperature, after which they were centrifuged at 3000 g for 15 minutes. The separated sera were aliquoted and stored at -80ºC.

Laboratory analysis

The separated sera were aliquoted and stored at -80ºC until analysed. Total serum 25-hydroxy vitamin D concentration was assessed by direct, competitive chemiluminescent immunoassay in a commercial laboratory enrolled in the Royal College of Pathology Australia (RCPA) external Quality Assurance program for vitamin D analysis using the DiaSorin LIAISON analyser (DiaSorin Inc, Stillwater, MN, USA). All time point samples for each participant were measured in the same batch to reduce interassay variation.

Activity

Physical activity was measured using the Community Healthy Activities Model Program for Seniors (CHAMPS) questionnaire (Stewart et al., 2001) (see Chapter 3.5.2).

Sunlight exposure

The hours of exposure to sunlight were recorded for one week in each season in a questionnaire similar to the CHAMPS format developed by the research team. Usual sun behaviour factors were included in a questionnaire to determine the amount of skin exposed, providing a numeric value based on four questions with a rating scale (minimum 3, maximum 12; higher values indicating more skin protection behaviours used). Participants were to rate the four following questions with a value as to if, in the last week they had never (1), sometimes (2) or always (3)

Wore a hat

Avoided the sun

Wore sunscreen

Wore clothing to protect from sun exposure

Both questionnaires were administered by and checked at each visit by a researcher to ensure that all questions had been answered. A copy of the questionnaires is included in Appendix 1b.

Falls diary

Each participant received a printed calendar with individualised code for the 15 months of the study on which they were asked to report any falls and associated details by marking the date. A free return paid envelope was provided for ease of return. On the reverse side of the calendar, information about the type of fall and any injuries that resulted from it were recorded. If medical attention was sought this was also recorded. Diaries were posted back monthly.

7.2.4 Statistical Analyses

Annual cyclic trends were investigated by fitting a sine wave formula to data for each outcome measure. The amplitude of the seasonal variation (in percentage change), the timing of the peak values and the annual mean values (mesor) were estimated using repeated measures non-linear regression, adjusted for age, gender and starting cohort. The validity of the fit of the sine wave formula was judged against the mean values at each season visit point estimated by repeated measures mixed methods linear regression (using unstructured covariance), adjusted for the same covariates. As well, repeated measures mixed methods linear regression was also used to estimate the associations between ankle and knee muscle strength (as outcomes) and vitamin D and physical activity, adjusted for age of participants from the commencement of the study. Similar regression modelling was used to estimate association of annual mean ankle and knee strength with fall incidence as an outcome. For comparison, seasonal data for falls was grouped into autumn and winter and compared to spring and summer [14]. All analyses were performed using Stata SE11.1 (StataCorp, College Station, Texas USA).

7.3 *Results*

7.3.1 Participants

Ninety-eight participants enrolled in this study. Eighty-eight people were included in the final analysis. Two people did not attend appointments, three suffered adverse medical events (neurological and cardiovascular), and three were overseas at testing times. Two participants attended testing, but were not able to perform the physical tests due to musculoskeletal pain (knee osteoarthritis). Sixty-two per cent of participants reported one or more chronic health conditions; the commonest of these being hypertension (30%), arthritis (14%) and cardiovascular disease (9%). All participants were independently living and mobile. Baseline characteristics for participants who completed the study are reported in **Table 7-1.**

7.3.2 Descriptive Statistics

Significant seasonal variations were observed in ankle strength, vitamin D, physical activity and sun exposure (all $P<0.001$), with the highest values observed in summer.

Table 7-1. Baseline characteristics of participants who completed all assessments

Variable	**Mean (SD)**	
Age (yrs.)	69.2 (6.5)	
Weight (kg)	74.6 (12.0)	
Height (cm)	165 (8.9)	
		%
Living alone		10%
% in Full time work		6%
% with chronic health conditions		62%
% men		11%
% more than 4 medications		26%

However no seasonal change was noted in quadriceps strength. **Table 7-2** presents baseline data for participants for these variables, as well as mean annual value (mesor) and amplitude of seasonal change in mesor, with 95% confidence intervals.

The peak value for vitamin D levels was seen four weeks after the peaks in the other three variables, with no significant difference in the timing between ankle strength, activity and sun exposure (**Figure 7-1**).

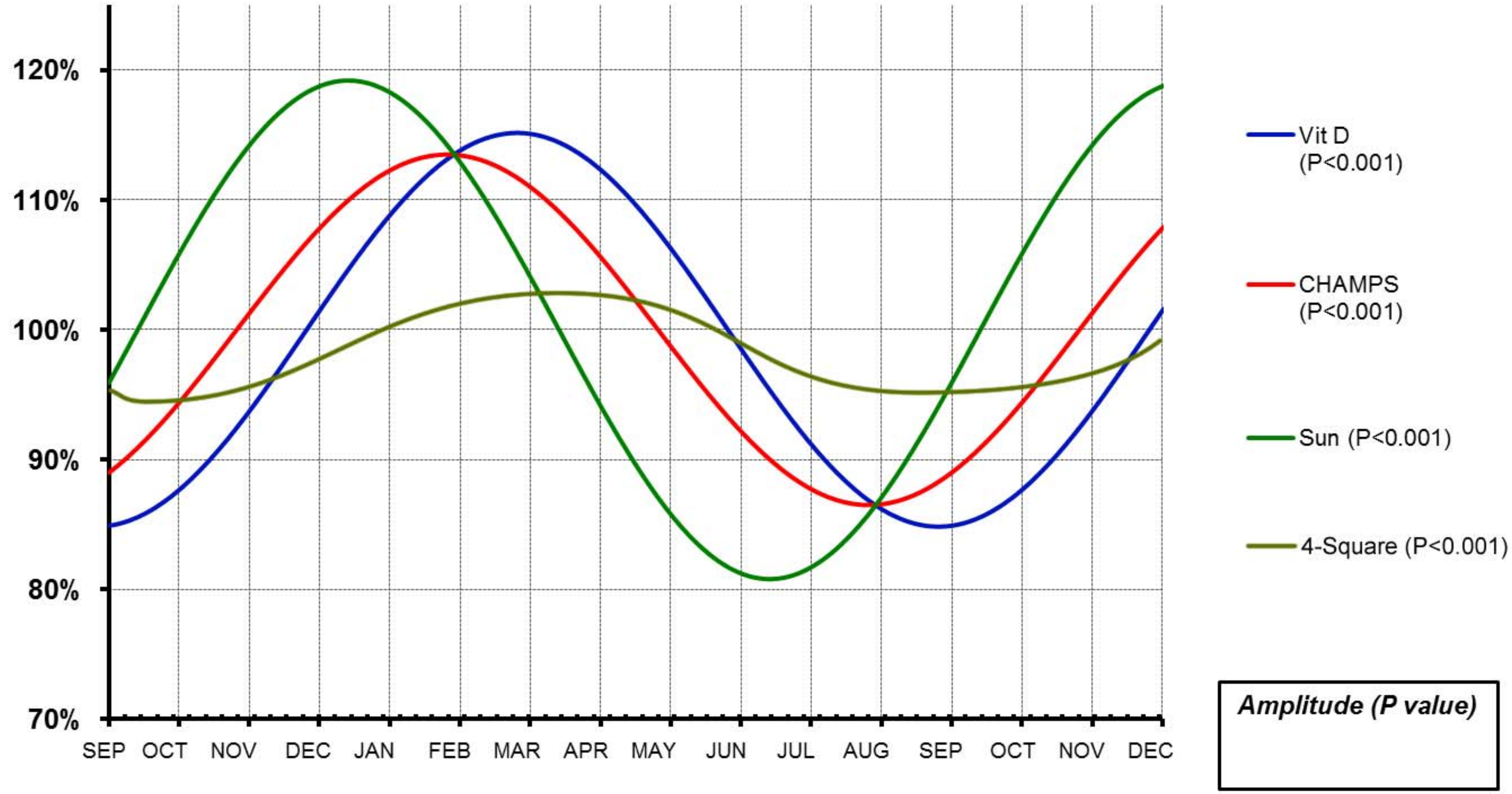

Figure 7-1. Seasonal variation in vitamin D, ankle strength, activity (CHAMPS) and time spent outside (sun).

Data presented as percentage change around mesor (expressed as 100 per cent). Mesor is annual mean value.

Table 7-2. Baseline performance of participants at visit 1 and mesor (annual mean value)

Variable	**Mean (SD) Visit 1**	**Mesor**	**Amplitude of seasonal change mean (95%CI)**
Ankle Strength (Nm)	11.3 (4.2)	10.1 (2.7)	8% (6 to 11)
Knee Strength (Nm)	19.7 (7.4)	19.2 (4.7)	2% (0 to 4)
Vitamin D (nmol/L)	58.1 (19.3)	59.2 (18.2)	15% (12 to 18)
Activity (MET Hours/week)	55.8 (37.3)	50.0 (25.8)	13% (6 to 18)
Sun Exposure (hours)	6.4 (3.4)	6.2 (2.4)	20% (14 to 26)

Strength

Ankle dorsiflexor strength showed significant ($P<0.001$) variation across the year, with the highest value seen in midsummer (January in southern hemisphere) and the magnitude of the variation at 8% (95% CI: 6 to 11%). Quadriceps strength did not vary over the year, ($P=0.53$). To explore these effects, regression analysis was undertaken for age and season that showed significant association between changes in ankle strength and knee strength (0.2 kg per 1SD of knee strength, 95%CI 0.17 to 0.29; $P<0.01$). Ankle strength was associated with physical activity (mean 0.38 kg per 1SD of CHAMPS; 95%CI 0.05 to 0.72; $P=0.026$) and ankle strength and sun exposure (mean 0.34 kg per 1SD of sun exposure; 95%CI 0.07 to 0.2; $P=0.014$). Knee strength was only associated with physical activity (mean 0.02 kg per 1SD of CHAMPS; 95%CI 0.004 to 0.03; $P=0.012$). Neither ankle strength ($P=0.16$) or knee strength ($P=0.69$) were associated with vitamin D. Low ankle strength was associated with increased incidence of falling (mean -0.004 falls per 1SD of ankle strength, 95%CI -0.007 to 0; $P=0.047$).

Vitamin D

The magnitude of the seasonal variation in serum vitamin D was 15%, with the highest values seen at the end of summer (P<0.001). Serum levels of vitamin D are presented in **Table 7-3.**

Activity and Sun Exposure

There was a 13% (95%CI 6 to 18) variation in physical activity across the year with participants being significantly more active in summer than in winter (P<0.001).

Table 7-3. Vitamin D levels at different timepoints throughout the year

Season	**Mean Vitamin D levels (nmol/L)**
End of Spring	59.3
End of Summer	68.2
End of Autumn	58.1
End of Winter	49.3
End of Spring	58.7

Peak activity occurred in January (1.3 more MET hours/day, in summer, compared to winter) coinciding with both the peak in ankle strength and the hours spent outside. Activity and sun exposure showed a positive association (r=0.4, P<0.001). During summer, participants spent 20% (95%CI 14 to 26) more time outside (P<0.001).

7.4 *Discussion*

The results of this study demonstrate moderate seasonal variations in ankle muscle strength, vitamin D levels and physical activity, with the peak and troughs in vitamin D levels occurring over one month after the peak and troughs in the other measures. Increased ankle strength is associated with increased activity and time spent outside. Low ankle strength showed association with fall incidence.

The greatest values for ankle strength occurred in summer, and these changes coincided with the highest values for physical activity. The lowest levels of ankle strength and activity were recorded in winter, with a 13% reduction in physical activity seen simultaneously with an 8% significant reduction in ankle strength. Reductions in ankle strength observed in the winter months may be important contributors to trip related falls. Up to 53% of falls in a similarly aged community-dwelling group were found to be as a result of tripping (Blake et al., 1988). For those older adults who are less active outside in the winter months, because of either poor weather conditions or limited daylight hours, inclusion of activities to improve dorsiflexion strength may be beneficial, and this warrants further investigation. A recent large randomised trial incorporating foot and ankle exercise as part of a multifaceted podiatric intervention resulted in increased ankle muscle strength (particularly inversion) and reduced falls (Spink et al., 2011b). Values for ankle dorsiflexion strength changes in this study also approached significance (0.063) with concurrent improvements in balance (Spink et al., 2011b). The clinical significance of the 8% change in dorsiflexion strength in this study is difficult to quantify, but a 16% improvement in this parameter post resistance training was shown to concurrently occur with a decrease in fall risk of 57.3% (Liu-Ambrose et al., 2004).

Lower limb strength is one of the most important fall risk factors in older adults (Rubenstein, 2006). The temporal stability of knee strength found in this study has good implications for fall risk throughout the year in this cohort. The fact that the quadriceps and tibialis anterior muscles behave differently over the year in terms of strength changes, suggest that year round incidental activities (sit to stand, routine home activities such as cleaning and gardening, shopping, and climbing stairs) that place a moderate demand on proximal muscles such as hip and knee extensors, may have a greater effect on preserving proximal muscle strength than ankle muscle strength through winter, irrespective of vitamin D status. As the peak for vitamin D levels occurs over a month after the peak for muscle strength, sufficient levels of vitamin D to maximise ankle strength may have been reached prior to the peak of vitamin D, and additional increases in vitamin D did not have any additional effect on strength measures.

The older adults who participated in the current study were 13% more active during the summer months, increasing their activity by an average of 1.3 MET hours per day in January compared to August. Evidence is growing to indicate that physical activity is important in maintaining physical function and mobility by impacting both muscle strength and balance in older adults, with some authors suggesting the positive sequellae of this may be fall prevention (Gregg et al., 2000). In this study, participants increased their activity levels in summer months, when longer daylight hours and warmer weather provide greater opportunities for activity outdoors, supporting previous research that found that day length and sunshine duration had a significant influence on levels of physical activity (Sumukadas et al., 2009)

Limitations

This study was performed in a group of a community-dwelling older adults, who were physically capable of changing their outside activity levels in response to positive and negative environmental factors. As such the results are not able to be generalised to other groups of older adults, particularly those who are institutionalised or frailer and less likely to vary the time they spend outside.

7.5 *Conclusion*

For clinicians and researchers who provide interventions designed to improve leg strength this research provides evidence of clear seasonal variation in ankle dorsiflexion strength that needs to be considered when measuring strength changes as part of any intervention. The reduced ankle dorsiflexor strength in winter months may predispose older people to increased risk of tripping-related falls, and this may warrant investigation as part of a multi-faceted falls prevention program.

8 POSTURAL SWAY REMAINS STABLE DESPITE SEASONAL VARIATION IN VITAMIN D IN PRE-FRAIL OLDER ADULTS

8.1 *Background*

Balance impairment is an important fall risk factor (Rubenstein, 2006) and increases in range in postural sway in the ML direction in older adults are associated with increased fall risk and rates (Bergland et al., 2003). Multivariate analysis has shown serum vitamin D levels to be independently associated with postural sway (Dhesi et al., 2002). In individuals with suboptimal levels of vitamin D, postural sway improves after supplementation (Dhesi et al., 2004, Muir et al, 2011), independently of changes to fall rate or number of people falling. Both epidemiological and longitudinal studies have shown that vitamin D levels show seasonal variation (van der mei et al., 2007, Pasco et al., 2004). Lowest levels of serum vitamin D are recorded towards the end of winter, approximately four weeks after the shortest day of the year (Pasco et al., 2004). Fall rates have been shown to decrease post supplementation with vitamin D in older adults with previously insufficient levels (between 22 and 49nmol/L) (RaR 0.72, 95% CI 0.55 to 0.95) (Cameron et al., 2010).

There are many factors affecting fall risk for older individuals and although these may be different for inside and outside falls (Pajala et al., 2008), strength and balance remain two important physical fall risk factors. A recently published review of the literature supports an assertion that age-related changes in postural reactions may be related to vitamin D status – mediated through either central nervous system integration or anti-gravity muscles as the effectors in postural responses (Annweiler et al., 2010).

The winter season sees an increase in injuries from falls and in the number of accidental deaths from falls (Mirchandani et al., 2005). Fracture rates from falls in older adults also increase at the end of the winter season (Pasco et al., 2004), following two to eight weeks after the nadir in serum vitamin D levels. Research into seasonal variation in fall rates, however, has produced disparate results. Some studies report an increased rate of falls, for both inside and outside falls (Mirchandani et al., 2005, Yeung et al., 2011). However significant seasonal variation in fall rates were not found in a three year study (Pasco et al., 2004), while in a second study, seasonal variation in fall rates was reported in women, but not in men (Campbell et al., 1988).

Co-incident static balance changes with any potential increased fall rates in winter have not been previously reported. The aim of this study was to determine differences in static balance (postural sway), vitamin D, incidence of falls and type of fall serially at the end of each season over a 12 month period, in older community living adults. A secondary aim was to determine associations between seasonal variations in these variables.

8.2 *Methods*

8.2.1 Participants

Independently-living community-dwelling adults aged between 60 and 85 years were recruited through local print media and community clubs. All participants were able to ambulate independently. Exclusion criteria included recent or current acute medical conditions, or an uncontrolled chronic condition. Daily intake of oral supplementation of vitamin D of greater than 800IU was also an exclusion criterion. Participants were also excluded if they had a history of neurological disease (including stroke), and were withdrawn if they suffered a medical condition while participating in the study that would impact on their ability to perform the physical tests. Liver and kidney disease both impact vitamin D metabolism, and any potential participants with either of these conditions were excluded.

A-priori sample size calculation was based on a previous study reporting ML sway range in a sample of community-dwelling older adults (Bird et al., 2009) and this indicated a minimum requirement of 81 completed participants (minimum effect size 2.5 mm sway; SD 8mm; power 0.8, alpha 0.05). Ninety eight participants were recruited with the anticipation of a 15% drop-out rate.

8.2.2 Study Design

At the end of consecutive seasons, static balance, fall rate and vitamin D status were measured within a longitudinal study design. Data was collected from end of spring 2009 to the end of spring 2010, with collection of data timed to coincide with expected peaks and troughs in serum vitamin D levels (Pasco et al., 2004) in Australia at latitude 41 degrees south (Tasmania).

8.2.3 Procedure and Outcome measures:

Balance

Postural sway range in the ML sway direction was measured with the AMTI force platform using methodology described in Chapter 3.3.1.

Fall rate and injury

Each participant received a printed calendar with individualised code for the 12 months of the study on which they were asked to report any falls and associated details by marking the date. Diaries were returned each month via a free return paid envelope. Information about the type of fall, any injuries that resulted and if medical attention was sought, were recorded.

Vitamin D sampling and analysis

Venous blood samples were collected and processed as described in Chapter 7.2.3.

8.2.4 Statistical analysis

Mixed methods Poisson regression was used to determine associations between the variables of postural and dynamic balance and falls, fall injuries, and vitamin D. Subgroup analysis for the cohort with insufficient levels of vitamin D (<25nmol/L) was also performed. For comparison, seasonal data for falls was grouped into autumn and winter and compared to spring and summer (Yeung et al., 2011).

8.3 *Results*

8.3.1 Participants

Data from 88 participants (79% female) are included in the final analysis. Five people did not attend appointments, and five people could not complete testing because of medical events. The participants had a mean (SD) age of 69.2 (6.5) years and BMI 27.4 (3.9) $kg.m^{-2}$. All participants were living in their own homes independently, with only 10% being sole occupants. Common chronic controlled health conditions included arthritis (14%), and hypertension and cardiovascular disease (39% combined). Twenty-six percent of the participants reported use of more than four medications.

8.3.2 Descriptive Statistics

Balance

Postural sway data for the five time points are provided in **Table 8.1**. All four balance measures had highest sway scores (poorest balance) at the first end of spring measurement. All other seasonal measures were significantly different from this first time point (all P<0.05), but no subsequent significant difference was seen after any other seasonal measures, indicating a lack of seasonal variation in this outcome (P>0.05). No associations between postural sway and vitamin D were observed (all P>0.05). Increased postural sway was associated with fall injuries (IRR 1.59 (95%CI 1.14 to 2.24) (P=0.007), but not fall rates (IRR 1.36 (95%CI 0.95 to 1.97, P=0.09).

Vitamin D

Vitamin D levels for each of the seasons are reported in **Table 8-1**. There was 15% variation in this variable over the year, with a peak at the end of summer, and the lowest values at the end of winter. Subgroup analysis of those with deficient levels (<25nmol/L) was performed. When adjusting for low levels of vitamin D and order effects, postural sway appeared significantly greater in older participants (P<0.001) and female participants (P=0.047). Within this subgroup of vitamin D deficient individuals, seasonal fall risk was calculated. A possible increased risk of falling was seen with those with deficient levels in the different seasons (IRR 0.98 spring {95%CI 0.12 to 7.83; P>0.9}, 2.89 summer {95%CI 0.94 to 8.92; P=0.07}, 4.29 autumn {95%CI 0.5 to 36.5; P=0.18} and 1.72 winter {95%CI 0.69 to 4.28; P=0.24}). However, the numbers of falls was insufficient to be certain.

Falls

Thirty-three per cent of the cohort (29 people) fell at least once, with ten per cent of the whole group falling multiple times (eight people). Over the duration of the study, 48 falls were recorded; 14 (29%) of these occurred inside the house, and 34 occurred out of doors (71%). Six falls were due to fainting or dizziness, and 40 due to trip-related events, with one categorised as being pushed over (by a horse) and one not able to be categorised. Twenty-eight falls (58%) resulted in injury, but with only four (8%) requiring medical treatment (including one fracture). Further detail on seasonal variation in location and type of fall is provided in **Table 8-2**. There were significantly fewer falls during spring than any other season (P=0.01). Most falls occurred in May. When falls data were combined from autumn and winter seasons, and compared to the combined spring and summer seasons, there were more falls reported in the combined autumn and winter seasons (30 compared to 18, P=0.084). Less injuries were recorded in spring than any other season (P=0.02), with no other seasonal differences recorded.

Table 8-1. Variations in Vitamin D and dynamic and postural balance over 5 seasons.

Variable	End of Spring 2009	End of Summer 2010	End of Autumn2010	End of Winter 2010	End of Spring 2010
ML sway EO (cm) mean (SD)	1.9 (0.7)	1.2 (0.6)	1.3 (0.5)	1.1 (0.5)	1.1 (0.5)
Change from season 1		-0.6 (-0.7 to -0.5)*	-0.6 (-0.7 to -0.4)*	-0.8 (-0.9 to -0.6)*	-0.7 (-0.8 to -0.4)*
ML sway EC (cm) mean (SD)	2.1 (0.9)	1.4 (0.7)	1.4 (0.7)	1.3 (0.8)	1.4 (0.8)
Change from season 1		-0.7 (-0.8 to -0.6)*	-0.7 (-0.8 to -0.6)*	-0.8 (-0.9 to -0.6)*	-0.7 (-0.9 to -0.6)*
Foam ML (cm) sway EO mean (SD)	3.8 (1.2)	2.8 (1.1)	3.0 (1.2)	2.4 (0.8)	2.6 (0.8)
Change from season 1		-1.0 (-1.2 to -0.7)*	-0.8 (-1.0 to -0.5)*	-1.2 (-1.5 to -1.0)*	-1.2 (-1.4 to -0.9)*
Foam ML (cm) sway EC mean (SD)	6.8 (2.7)	5.0 (1.7)	4.7 (2.1)	4.6 (1.9)	4.8 (1.9)
Change from season 1		-1.7 (-2.3 to -1.2)*	-2.1 (-2.6 to -1.5)*	-2.1 (-2.8 to -1.5)*	-2.1 (-2.8 to -1.3)*
Vitamin D (nmol/L) mean (SD)	60 (19)	68 (21)*	58 (21)	52 (21)*	59 (20)
Change from season 1		8 (6 to 11)	-2 (-5 to 1)	-8 (-11 to -5)	-2 (-5 to 1)

ML=Medio-lateral, EO=Eyes Open, EC=Eyes Closed, cm=centimetre.
Data presented as Mean (SD), Changes from the season 1 (end of spring 2009) presented as Mean change (95%CI).
*(P<0.05).

Table 8-2. Fall incidence, venue, injury and cause reported grouped by season.

Season	Single Falls	Multiple falls	Total number of falls	Inside	Outside	Injuries	Faint
Spring	6	0	6	0	6	3	1
Summer	12	0	12	1	11	7	2
Autumn	15	2x2	19	9	10	12	1
Winter	11	0	11	4	7	6	2

8.4 *Discussion*

Seasonal variation in postural sway was not observed, despite significant seasonal variation in serum vitamin D levels, with higher serum levels recorded in summer. There was no relationship between postural sway and vitamin D. There was a significant relationship between postural sway and the number of injurious falls observed, with lower values for sway range (i.e. better stability) associated with less fall injuries. The overall fall rates were higher in autumn/winter than spring/summer.

There was no seasonal variation in postural sway under any of the four static balance test conditions measured (eyes open and closed on a firm surface or foam surface). Postural sway range has been used to identify those people with balance impairment (Maki et al., 1994), and it may be useful in describing the fall-risk status of a particular individual. Our data indicates that postural sway does not appear to be subject to changes across the year within a participant. It has been suggested that this measure is important in describing sensorimotor deficits rather than functional abilities (Hughes et al., 1996), and hence may not be subject to changes that may occur due to altered patterns of activity or sunlight exposure seen seasonally.

Medio-lateral sway range has been shown to be an independent risk factor for indoor falls (Pajala et al., 2008). In our study, a lower proportion of falls occurred indoors (29%) compared to outdoors (71%), and this is similar to other studies where more healthy populations have been reported as having a greater proportion of falls being outdoor falls (74%; Hill et al., 1999). The low number of falls may be a reason why no association between sway range and fall incidence was seen. A trend for this association was evident (P=0.09) and a larger sample size may have found a significant relationship between these two variables, as this study was powered to determine ML sway changes, not fall rates. An association between increased sway range and number of falls resulting in injuries was recorded in our study, reinforcing the importance of this measure for those most at risk of injury.

Overall there was no significant relationship found between postural sway and vitamin D. Postural sway has been linked to low levels of vitamin D (Pfeifer et al., 2000), and it may be that even at their lowest levels, the levels of vitamin D were sufficient to not adversely influence postural sway in participants in this study. In the current study, postural sway was greater in participants who were older and female from the subgroup that had insufficient levels of vitamin D (<25nmol/L). An increased risk of falling was seen in this sub-group as well. Each of the parameters of this group (increased age, female gender, low vitamin D and increased postural sway) were all independent fall risk factors. This reinforces that sway characteristics for each individual may be reflective of their functional capacity, which is unique to them and not subject to seasonal change. It may be a less sensitive measure of balance performance in this population.

Annual rates of falling for adults over 65 have been reported as between 30% (Tinetti and Williams, 1998) and 40% (Rubenstein, 2006) and although our cohort includes some adults between the ages of 60 and 65, with a mean age of 69 years, and a fall rate of 33 per cent, our population appears to be representative of older community-dwelling adults in terms of fall rate. Fall rates in older adults over 75 years have been shown to vary seasonally (Yeung et al., 2011), but consistent data for the general population of healthy older community-dwelling adults has not been previously reported. Previous research has grouped the peak seasons of winter and autumn together and found differences in fall rates (Yeung et al., 2011). Manipulation of our data in a similar way reveals that there were 50% more falls during the autumn/winter half year compared to spring/summer (**Table 8-2**). This does not inform us as to the reason for falling as much as looking at the contexts for falling during the different times of the year. These seasonal differences may be related to seasonal variation in intrinsic fall risk factors such as vitamin D, physical activity and muscle strength (Chapter 7) as well as seasonally related environmental factors (e.g. weather, temperature). Further research needs to investigate interventions to address potentially modifiable factors to reduce the increased fall risk in the autumn / winter period.

Our data indicates a higher rate of falls in summer than has previously been reported (Yeung et al., 2011), perhaps due to activity characteristics of our cohort. Summer and winter falls have also been reported to differ between the genders, with more men falling due to slips in winter, and more women falling due to trips in summer (Berg et al., 1997). The high proportion of women in our study (79%) may be a factor in the high rate of summer falls observed. Another factor to consider is the relationship between fall status and vitamin D. Although 60nmol/L has been determined to be the cut off for fall-risk function (Bischoff-Ferrari et al., 2009), 16/48 falls (33%) occurred in participants in this study whose vitamin D was above that cut off level. This may be explained by the higher proportion of summer time falls observed in our study. During the summer months, with longer hours of daylight at this latitude, a large proportion of the falls occurred out of doors (13 of the 14 falls - 93%) (**Table 8-2**). In contrast, in winter out-of-doors fall rate was reduced to 64%, indicating a higher winter time proportion of inside falls. For our generally healthy study population it is likely that participants were engaging in outdoor activities with higher associated risk of falls during the warmer weather: for example, several summer falls occurred while bushwalking.

Fall injuries, especially fractures, have been found to increase in winter; this includes both inside (hip) and out-of-doors falls (wrist) (Bischoff-Ferrari et al., 2007). Studies in the area of seasonal variation in fracture rates provide good evidence for increased fracture rates from falls in winter, but these appear in populations with older participants than ours (mean age over 75 years) (Mirchandani et al., 2005, Pasco et al., 2004). Our study recorded only a few injuries that required medical attention, hence making it difficult to compare serious fall injury data to other published research. Serious injuries have been reported to occur in 10% of falls (Tinetti, 2003), so our data presents a relatively low number of serious injuries, despite reporting an expected number of actual falls.

Limitations

Although this study aimed to recruit independently living community-dwelling older adults, bias in the sample may be present, as volunteers to this type of research project may be more robust than the community members at large. This study highlights that measurement of postural sway alone does not give a complete picture of balance, and the inclusion of dynamic balance measures may improve knowledge in seasonal variation in function.

8.5 *Conclusion*

Postural sway remained consistent over the year despite significant variations in vitamin D levels between seasons. Higher sway range was associated with higher rates of injurious falls. Low and non-significant relationships to vitamin D levels were found with postural sway and fall incidence. This group presented with a low number of falls that resulted in serious injury, which may be due to many falls occurring in summer, when vitamin D status was higher. This study adds to the awareness of seasonal variations in falls, to assist health professionals in advising older adults of caution at times of peak fall incidence.

9 DISCUSSION AND CONCLUSION

9.1 *Summary*

This thesis comprised of four studies that investigated several different types of exercise interventions and annual cyclic variation on a range of intrinsic physical fall risk factors including lower limb strength, balance, activity and vitamin D status. The first two studies investigated the immediate and longer term effects of progressive resistance training and flexibility training on balance, strength and activity. The third study investigated the effect of a Pilates intervention on balance, strength and activity. The final study examined the effects of season and the impact of different daylight length on activity, balance and strength while measuring exposure to sunlight directly (in hours of exposure) and via serum vitamin D levels.

9.2 *Discussion*

Accidental falls affect the quality of life of older adults, with important personal and social costs to individuals and our health care providers. Current literature reveals that the age-related decline in strength and balance impacts importantly on an individual's fall risk, function and independence and need to be prime intervention targets to minimise future falls. Exercise is an important approach to slowing or reversing age related declines in muscle strength and balance. Exercise also has a range of other potential health benefits for older people including reduced mortality and reduced morbidity, (for example, reduced risk of cardiovascular disease, and reduced risk of some cancers).

Although exercise that targets balance and muscle strength has been shown to improve both of these factors, benefits from participating in targeted exercise programs depends on a range of program parameters including;

- type of exercise (resistance, balance, flexibility, cardiovascular),
- context of exercise (group or individual, single or multi-component, home or other venue),
- dosage characteristics (including intensity, length of intervention or frequency and adherence).

Concurrently the characteristics of the target population needs to be considered when measuring benefits from participation, as this impacts on the effectiveness of particular programs. One important characteristic is basal activity level. Even in relatively well older people, health promoters should note that there are benefits to targeting this population with different exercise approaches to increase activity.

Three different exercise approaches (resistance training, flexibility training, and Pilates) have been investigated in the studies in this thesis, that provide support for wider uptake of each of the exercise approaches. While participants in the resistance training group improved their strength over the intervention period, both the flexibility training group and Pilates group improved in balance parameters without improvements in strength. Consequently it is likely that different mechanisms exist between these training protocols in producing the observed improvements in balance. Results from this thesis suggest that progressive resistance exercise programs, flexibility training programs and Pilates classes are likely to be of value to older adults looking to improve their stability and have positive functional implications for physical fall-risk factors. However further research would be required to delineate the particular mechanisms responsible for the improvements recorded in this thesis. In light of the findings of benefits of flexibility training to balance, it must now be considered that flexibility programs are not suitable as 'control' exercise programs when balance is an outcome measure of any future study. These results reinforce the varied positive outcomes associated with different exercise approaches, and a positive benefit of the growing number of exercise approaches that have been shown to have some common and different health outcomes. One additional benefit is the choice that this gives both health professionals and older people with exercise options to achieve their desired health benefits. Choice of several exercise approaches is one factor likely to increase initial uptake of participation in an exercise program.

Although many studies have reported positive outcomes on physical performance measures for older people in the short term, relatively few have investigated longer term effects. Sustained longer term engagement in exercise programs is recommended to maximise long term health gains associated with short term programs (Müller-Riemenschneider, 2008). Motivation to continue participation in organised exercise programs depends on the benefits that people attain during earlier stages of the program. These include quantifiable changes in terms of strength and balance as well as the perception of benefits that the participants describe. For the cohort recruited for the first two studies there was a significant difference in the changes in muscle strength of participants at the end of the intervention (short term) between those who continued and those who ceased the relevant exercise program long term. This has implications for monitoring within a program to ensure that maximum benefit is reached. The role of the instructor in individualising progression within a program would be a good focus for future research. Adherence to long-term changes in exercise behaviour should be an important focus for future research.

Current recommendations for exercise interventions to achieve a reduction in falls include a program load of at least 50 hours (Sherrington et al., 2008). For researchers who are measuring strength and balance before and after an intervention that may continue over several seasons, knowledge about natural seasonal variation in the measured parameters will assist researchers in determining true meaning behind any observed changes. As both strength and balance have been shown to be associated with vitamin D, a rationale for seasonal variation in both variables exists. No seasonal variation in strength within the quadriceps (commonly measured as a fall risk factor) was seen in the study reported in this thesis. Likewise postural sway did not show seasonal variation. Small changes in dynamic balance were seen, but at ± 4% of the mean, the clinical implications of this are small. More substantial seasonal variation in ankle muscle strength (±8%), physical activity (±13%) and time spent out of doors (±20%) was seen, with all of these variables at their peak during summer. This peak occurred 4 weeks prior to seasonal peaks in vitamin D. The observed variation in ankle strength of ± 8% may be more clinically relevant, with association between reduced ankle strength and fall incidence seen in this cohort (Chapter 7). Many studies use quadriceps strength as a measure of lower limb strength, but the fact that ankle dorsiflexion and knee extension strength show different change-behaviours over the year and the likely greater involvement of ankle muscle weakness in trip related falls mean that both of these should be considered in future research.

The positive benefit of outdoors activity during summer may be useful for those promoting physical activity to assist older adults to remain active and improve physical fall risks. These results are quite specific to the latitude of the study as well as the population, and expansion of this research to other latitudes would enhance our overall knowledge of seasonality of physical fall risk factors. Inclusion of ankle strength testing and ankle flexibility may be useful foci for future fall risk intervention assessment measures, to try to delineate out mechanisms for changes in fall risk.

Seasonal change in vitamin D levels, activity and ankle strength, with higher falls in the autumn/winter seasons compared to spring/summer seasons were recorded. The number of summer time falls were higher than expected, occurring more in the out of doors environment. This may reflect the healthy sample population that volunteered for this study. A lower number of serious injuries from falls were reported; perhaps because such a high proportion occurred during summer, when vitamin D levels where higher. Changes in physical activity, time spent out-of-doors and vitamin D levels that occur due to large variations in daylight at this latitude have important policy making ramifications for encouraging adults to successfully age by staying active, in particular out of doors. The low levels of vitamin D in summer overall may have important consequences for other health domains, and support the promotion of improved public awareness of requirements of an adequate vitamin D status for optimum health.

9.3 *Directions for future research*

Not all progressive resistance training programs have shown improvements in balance. Our program included a relatively long intervention period and ongoing progression of weights lifted, which was supervised closely. Both of these parameters may have impacted on the success on this program, and may inform future research protocols. The flexibility program in this study showed improved balance outcomes. To assist in delineating and differentiating mechanisms of balance improvement, it would be valuable to measure concurrently any changes in ankle range of movement and ankle strength with balance pre and post a flexibility intervention, perhaps compared to another form of exercise like progressive resistance training.

Pilates has been shown to improve balance in community-dwelling older adults. Although the mechanisms for this are not fully understood, it may be worthwhile investigating this form of exercise for different populations, including those who have musculoskeletal conditions (for example knee osteoarthritis) or those with neurological conditions (for example Parkinson's disease). The use of a cross-over study design is not advised because of the longer lasting balance benefits shown in this study.

As many older adults do not meet the ACSM guidelines for physical activity and exercise, more research into the domain of motivation for supporting uptake and sustained participation in new exercise behaviours is warranted.

As ankle strength may be important for trip related falls, an intervention study in winter to improve dorsiflexion strength and measure fall rate and type may provide more information about the relative importance of ankle strength in seasonal fall risk profiles. In addition, ML sway may be more dependent on hip abductor/adductor strength, and future studies should consider including both ankle and hip strength measures, not just knee extension strength when providing interventions for general 'lower limb' weakness.

Many of the participants in the vitamin D study had suboptimal levels even in the middle of summer, so it would be worthwhile determining if these participants changed their behaviour in response to being informed of their low levels of this substrate. Assessment of translation of research into changed health behaviours is not often undertaken, and could provide valuable insights.

9.4 *Conclusions*

Studies in this thesis have demonstrated that exercise can produce improvements in multiple domains of function and support previous research that examines the effects of several specific exercise regimes on physical fall risks. It includes the first RCTs designed to investigate exercise outcomes with a Pilates intervention in community-dwelling older adults. It extends this knowledge by also investigating the implications of seasonal variations in physical activity on the physical fall risk factors of balance and strength. This thesis supports the clinical construct that both static and dynamic balance measures are important for a comprehensive fall risk measurement by demonstrating that there are differences in the way these two parameters behave over an annual cycle (seasonally). This body of work lays some foundation for enhancing long term adherence to exercise by delineating factors that are important for ongoing participation in an exercise program after the formal (short term) intervention period has finished, including the physical benefits of improved strength. This informs program design for maximum impact of ongoing improvements or maintenance of the health of older adults.

10 REFERENCES

AAGAARD, P., MAGNUSSON, P. S., LARSSON, B., KJÆR, M. & KRUSTRUP, P. 2007. Mechanical muscle function, morphology, and fiber type in lifelong trained elderly. *Medicine and Science in Sports and Exercise,* 39, 1989-1996.

ABE, T., DEHOYOS, D. V., POLLOCK, M. L. & GARZARELLA, L. 2000. Time course for strength and muscle thickness changes following upper and lower body resistance training in men and women. *European Journal of Applied Physiology,* 81, 174-180.

AMIRIDIS, I., ARABATZI, F., VIOLARIS, P., STAVROPOULOS, E. & HATZITAKI, V. 2005. Static balance improvement in elderly after dorsiflexors electrostimulation training. *European Journal of Applied Physiology,* 94, 424-433.

ANNWEILER, C. & BEAUCHET, O. 2010. High-dose vitamin D repletion-related falls and fractures: An uncontrolled mobility gain? *Biofactors,* 36, 407-407.

ANNWEILER, C., MONTERO-ODASSO, M., SCHOTT, A., BERRUT, G., FANTINO, B. & BEAUCHET, O. 2010. Fall prevention and vitamin D in the elderly: an overview of the key role of the non-bone effects. *Journal of NeuroEngineering and Rehabilitation,* http://www.jneuroengrehab.com/content/7/1/50.

ANNWEILER, C., SCHOTT, A. M., BERRUT, G., FANTINO, B. & BEAUCHET, O. 2009. Vitamin D-Related Changes in Physical Performance: A Systematic Review. *Journal of Nutrition Health and Aging,* 13, 893-898.

ARENT, S. M., LANDERS, D. M. & ETNIER, J. L. 2000. The effects of exercise on mood in older adults: A meta-analytic review. *Journal of Aging and Physical Activity,* 8, 407-430.

BAKER, D. I., GOTTSCHALK, M. & BIANCO, L. M. 2007. Step by step: integrating evidence-based fall-risk management into senior centers. *Gerontologist,* 47, 548-54.

BALLARD, J. E., MCFARLAND, C., WALLACE, L. S., HOLIDAY, D. B. & ROBERSON, G. 2004. The effect of 15 weeks of exercise on balance, leg strength, and reduction in falls in 40 women aged 65 to 89 years. *Journal of the American Medical Women's Association,* 59, 255-261.

BALOH, R. W., JACOBSON, K. M., BEYKIRCH, K. & HONRUBIA, V. 1998. Static and dynamic posturography in patients with vestibular and cerebellar lesions. *Archives of Neurology,* 55, 649-654.

BALOH, R. W., JACOBSON, K. M. & SOCOTCH, T. M. 1993. The effect of Aging on Visual-vestibular Responses. *Experimental Brain Research,* 95, 509-516.

BANDURA, A. 1977. Self-efficacy: toward a unifying theory of behavioral change. *Psychology Review,* 84, 191-215.

BARNETT, A., SMITH, B., LORD, S. R., WILLIAMS, M. & BAUMAND, A. 2003. Community-based group exercise improves balance and reduces falls in at-risk older people: a randomised controlled trial. *Age and Ageing,* 32, 407-414.

BARRA, J., BRAY, A., SAHNI, V., GOLDING, J. F. & GRESTY, M. A. 2006. Increasing cognitive load with increasing balance challenge: Recipe for catastrophe. *Experimental Brain Research,* 174, 734-745.

BARRETT, C. & SMERDELY, P. 2002. A comparison of community-based resistance exercise and flexibility exercise for seniors. *Australian Journal of Physiotherapy,* 48, 215-219.

BATH, P. A. & MORGAN, K. 1999. Differential risk factor profiles for indoor and outdoor falls in older people living at home in Nottingham, UK. *European Journal of Epidemiology,* 15, 65-73.

BAUER, C., GRÃGER, I., RUPPRECHT, R. & GASSMANN, K. G. 2008. Intrasession reliability of force platform parameters in community-dwelling older adults. *Archives of Physical Medicine and Rehabilitation,* 89, 1977-1982.

BAUTMANS, I., VANTIEGHEM, S., GORUS, E., GRAZZINI, Y. R., FIERENS, Y., POOL-GOUDZWAARD, A. & METS, T. 2011. Age-related differences in pre-movement antagonist muscle co-activation and reaction-time performance. *Experimental Gerontology,* 46, 637-642.

BEAN, J. F., HERMAN, S., KIELY, D. K., FREY, I. C., LEVEILLE, S. G., FIELDING, R. A. & FRONTERA, W. R. 2004. Increased velocity exercise specific to task (InVEST) training: A pilot study exploring effects on leg power, balance, and mobility in community-dwelling older women. *Journal of the American Geriatrics Society,* 52, 799-804.

BEAUCHAMP, M. R., CARRON, A. V., MCCUTCHEON, S. & HARPER, O. 2007. Older adults' preferences for exercising alone versus in groups: Considering contextual congruence. *Annals of Behavioral Medicine,* 33, 200-206.

BENJUYA, N., MELZER, I. & KAPLANSKI, J. 2004. Aging-induced shifts from a reliance on sensory input to muscle cocontraction during balanced standing.

Journals of Gerontology Series A, Biological Sciences and Medical Sciences, 59, 166-171.

BERG, K., WOOD-DAUPHINEE, S., WILLIAMS, J. I. & GAYTON, D. 1989. Measuring balance in the elderly: preliminary development of an instrument. *Physiotherapy Canada,* 41, 304-311.

BERG, W. P., ALESSIO, H. M., MILLS, E. M. & TONG, C. 1997. Circumstances and consequences of falls in independent community-dwelling older adults. *Age and Ageing,* 26, 261-268.

BERGLAND, A., JARLNO, G. & LAAKE, K. 2003. Predictors of falls in the elderly by location. *Aging Clinical Experimental Research,* 15, 43-45.

BERNARDO, L. M. 2007. The effectiveness of Pilates training in healthy adults: An appraisal of the research literature. *Journal of Bodywork and Movement Therapies,* 11, 106-110.

BERNHARDT, J. & HILL, K. (eds.) 2005. *Science based reabilitation: Theories into practice,* Oxford: Elsevier.

BESNE, I., DESCOMBES, C. & BRETON, L. 2002. Effect of age and anatomical site on density of sensory innervation in human epidermis. *Archives of Dermatology,* 138, 1445-1450.

BIDDLE, S. & FOX, K. 2000. *Physical Activity, aging and psychological well being.,* London, Routlegde.

BIGELOW, K. E. & BERME, N. 2011. Development of a Protocol for Improving the Clinical Utility of Posturography as a Fall-Risk Screening Tool. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 66, 228-233.

BIRD, M., HILL, K., BALL, M. & WILLIAMS, D. 2009. Effects of Resistance and Flexibility Exercise Interventions on Balance and Related Measures in Older Adults. *Journal of Aging and Physical Activity,* 17, 444-454.

BIRD, M., HILL, K. D., BALL, M., HETHERINGTON, S. & WILLIAMS, A. D. 2011. The long-term benefits of a multi-component exercise intervention to balance and mobility in healthy older adults. *Archives of Gerontology and Geriatrics,* 52, 211-216.

BIRRELL, F. & FRANCIS, R. M. 2008. Invited Commentary: Physical Activity and Vitamin D. *American Journal of Epidemiology,* 168, 587-589.

BISCHOFF-FERRARI, H., BORSCHERS, M., GUDAT, F., DURMULLER, U. & STAHELIN, H. 2004a. Vitamin D receptor expression in human muscle tiddue decreases with age. *Journal of Bone and Mineral Research,* 19, 265-269.

BISCHOFF-FERRARI, H. A., CONZELMANN, M., STÃHELIN, H. B., DICK, W., CARPENTER, M. G., ADKIN, A. L., PEIFER, M. & ALLUM, J. H. 2006. Is fall prevention by vitamin D mediated by a change in postural or dynamic balance? *Osteoporosis International,* 17, 656-663.

BISCHOFF-FERRARI, H. A., DAWSON-HUGHES, B., STAEHELIN, H. B., ORAV, J. E., STUCK, A. E., THEILER, R., WONG, J. B., EGLI, A., KIEL, D. P. & HENSCHKOWSKI, J. 2009. Fall prevention with supplemental and active forms of vitamin D: a meta-analysis of randomised controlled trials. *British Medical Journal,* 339, 10.1136/bmj.b3692.

BISCHOFF-FERRARI, H. A., DIETRICH, T., ORAV, E. J., HU, F. B., ZHANG, Y., KARLSON, E. W. & DAWSON-HUGHES, B. 2004b. Higher 25-hydroxyvitamin D concentrations are associated with better lower-extremity function in both active and inactive persons aged >60 y. *American Journal of Clinical Nutrition,* 80, 752-758.

BISCHOFF-FERRARI, H. A., ORAV, J. E., BARRETT, J. A. & BARON, J. A. 2007. Effect of seasonality and weather on fracture risk in individuals 65 years and older. *Osteoporosis International,* 18, 1225-1233.

BISCHOFF-FERRARI, H. A., SHAO, A., DAWSON-HUGHES, B., HATHCOCK, J., GIOVANNUCCI, E. & WILLETT, W. C. 2010. Benefit-risk assessment of vitamin D supplementation. *Osteoporosis International,* 21, 1121-1132.

BISCHOFF, H. A., STAHELIN, H. B., DICK, W., AKOS, R., KNECHT, M., SALIS, C., NEBIKER, M., THEILER, R., PFEIFER, M., BEGEROW, B., LEW, R. A. & CONZELMANN, M. 2003. Effects of vitamin D and calcium supplementation on falls: A randomised controlled trial. *Journal of Bone and Mineral Research,* 18, 343-351.

BLAKE, A. J., MORGAN, K., BENDALL, M. J., DALLOSSO, H., EBRAHIM, S. B. J., ARIE, T. H. D., FENTEM, P. H. & BASSEY, E. J. 1988. Falls by elderly people at home- prevalence and associated factors. *Age and Ageing,* 17, 365-372.

BLOCH, F., THIBAUD, M., DUGUE, B., BREQUE, C., RIGAUD, A. S. & KEMOUN, G. 2011. Psychotropic Drugs and Falls in the Elderly People: Updated Literature Review and Meta-Analysis. *Journal of Aging and Health,* 23, 329-346.

BOHANNON, R. W., LARKIN, P. A., COOK, A. C., GEAR, J. & SINGER, J. 1984. Decrease in Timed Balance Test-Scores with Aging *Physical Therapy,* 64, 1067-1070.

BOLOGNINI, N., PASCUAL-LEONE, A. & FREGNI, F. 2009. Using non-invasive brain stimulation to augment motor training-induced plasticity. *Journal of Neuroengineering and Rehabilitation,* 6, 1-13.

BOSHUIZEN, H. C., STEMMERIK, L., WESTHOFF, M. H. & HOPMAN-ROCK, M. 2005. The effects of physical therapists' guidance on improvement in a strength-training program for the frail elderly. *Journal of Aging and Physical Activity,* 13, 5-22.

BOULGARIDES, L., MCGINITY, S., WILLET, J. & BARNES, C. 2003. Use of clinical and impairment based tests to predict falling by community dwelling older adults. *Physical Therapy,* 83, 328-339.

BOYLE, N., NAGANATHAN, V. & CUMMING, R. G. 2010. Medication and Falls: Risk and Optimization. *Clinics in Geriatric Medicine,* 26, 583-605.

BRANDON, C. A., GILL, D. P., SPEECHLEY, M., GILLILAND, J. & JONES, G. R. 2009. Physical activity levels of older community-dwelling adults are influenced by summer weather variables. *Applied Physiology Nutrition and Metabolism-Physiologie Appliquee Nutrition Et Metabolisme,* 34, 182-190.

BRANDON, L. J., BOYETTE, L. W., GAASCH, D. A. & LLOYD, A. 2000. Effects of lower extremity strength training on functional mobility in older adults. *Journal of Aging and Physical Activity,* 8, 214-227.

BRAUER, S., BURNS, Y. & GALLEY, P. 1999. Lateral reach: a clinical measure of medio-lateral postural stability. *Physiotherapy Research International* 4, 81-88.

BRAUER, S., BURNS, Y. & GALLEY, P. 2000. A Propspective Study of Laboratory and Clinical Measures of Postural Stability to Predict Community Dwelling Fallers. *The Journals of Gerontology,* 55A, M469-M476.

BRAUN, B. L. 1998. Knowledge and perception of fall-related risk factors and fall-reduction techniques among community-dwelling elderly individuals. *Physical Therapy,* 78, 1262-1276.

BROOKS, S. A. F., J 1994. Skeletal muscle weakness in old age:underlying mechanisms. *Medicine and Science in Sports and Exercise,* 26, 432-439.

BROWN, J. S., VITTINGHOFF, E., WYMAN, J. F., STONE, K. L., NEVITT, M. C., ENSRUD, K. E., GRADY, D. & STUDY OSTEOPOROTIC FRACTURES RES, G. 2000. Urinary incontinence: Does it increase risk for falls and fractures? *Journal of the American Geriatrics Society,* 48, 721-725.

BROWN, L., SHUMWAY-COOK, A. & WOOLLACOTT, M. 1999. Attentional demands and postural recovery: the effects of aging. *Journals of Gerontology. Series B, Psychological Sciences and Social Sciences,* 54, M165-M171.

BUCHNER, D., CRESS, M., DE LATEUR, B., ESSELMAN, P., MARGHERITA, A., PRICE, R. & WAGNER, E. 1997a. The effect of strength and endurance training on gait, balance, fall risk, and health services use in community-living older adults. *Journals of Gerontology. Series B, Psychological Sciences and Social Sciences,* 52, M218-M224.

BUCHNER, D. M., CRESS, M. E., DELATEUR, B. J., ESSELMAN, P. C., MARGHERITA, A. J., PRICE, R. & WAGNER, E. H. 1997b. A comparison of the effects of three types of endurance training on balance and other fall risk factors in older adults. *Aging-Clinical and Experimental Research,* 9, 112-119.

BUCHOWSKI, M. S., CHOI, L., MAJCHRZAK, K. M., ACRA, S., MATHEWS, C. E. & CHEN, K. Y. 2009. Seasonal changes in amount and patterns of physical activity in women. *Journal of Physical Activity and Health,* 6, 252-261.

BUITRAGO, C., VAZQUEZ, G., DE BOLAND, A. R. & BOLAND, R. 2001. The vitamin D receptor mediates rapid changes in muscle protein tyrosine phosphorylation induced by 1,25(OH)2D3. *Biochemical and Biophysical Research Communications,* 289, 1150-1156.

BULA, C. J., MONOD, S., HOSKOVEC, C. & ROCHAT, S. 2011. Interventions Aiming at Balance Confidence Improvement in Older Adults: An Updated Review. *Gerontology,* 57, 276-286.

BULLOCK-SAXTON, J. E., WONG, W. J. & HOGAN, N. 2001. The influence of age on weight-bearing joint reposition sense of the knee. *Experimental Brain Research,* 136, 400-406.

CALDWELL, K., HARRISON, M., ADAMS, M. & TRAVIS TRIPLETT, N. 2009. Effect of Pilates and Taiji Quan training on self-efficacy, sleep quality, mood, and physical performance of college students. *Journal of Bodywork and Movement Therapies,* 13, 155.

CALLISAYA, M. L., BLIZZARD, L., SCHMIDT, M. D., MCGINLEY, J. L., LORD, S. R. & SRIKANTH, V. K. 2009. A population-based study of sensorimotor factors affecting gait in older people. *Age and Ageing,* 38, 290-295.

CAMERON, I. D., MURRAY, G. R., GILLESPIE, L. D., ROBERTSON, M. C., HILL, K. D., CUMMING, R. G. & KERSE, N. 2010. Interventions for preventing falls in older people in nursing care facilities and hospitals. *Cochrane Database of Systematic Reviews*, CD005465.

CAMPBELL, A., BORRIE, M. J., SPEARS, G. F., JACKSON, S. L., BROWN, J. S. & FITZGERALD, J. L. 1990. Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. *Age and Ageing,* 19, 136-141.

CAMPBELL, A., ROBERTSON, M., GARDNER, M., NORTON, R. & BUCHNER, D. 1999a. Falls prevention over 2 years: A randomised controlled trial in women 80 years and older. *Age and Ageing,* 28, 513-518.

CAMPBELL, A. J., BORRIE, M. J. & SPEARS, G. F. 1989. Risk factors for falls in a community-based prospective study of people of 70 years and older. *Journals of Gerontology,* 44, M112-M117.

CAMPBELL, A. J., ROBERTSON, M. C., GARDNER, M. M., NORTON, R. N. & BUCHNER, D. M. 1999b. Psychotropic medication withdrawal and a home-based exercise program to prevent falls: a randomised, controlled trial. *Journal of the American Geriatric Society,* 47, 850-853.

CAMPBELL, A. J., ROBERTSON, M. C., GARDNER, M. M., NORTON, R. N., TILYARD, M. W. & BUCHNER, D. M. 1997. Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women. *British Medical Journal,* 315, 1065-1069.

CAMPBELL, A. J., ROBERTSON, M. C., LA GROW, S. J., KERSE, N. M., SANDERSON, G. F., JACOBS, R. J., SHARP, D. M. & HALE, L. A. 2005. Randomised controlled trial of prevention of falls in people aged ≥ 75 with severe visual impairment: the VIP trial. *British Medical Journal,* 331, 817A-820A.

CAMPBELL, A. J., SPEARS, G. F. S., BORRIE, M. J. & FITZGERALD, J. L. 1988. Falls, elderly women and the cold *Gerontology,* 34, 205-208.

CARTER, N. D., KHAN, K. M., MCKAY, H. A., PETIT, M. A., WATERMAN, C., HEINONEN, A., JANSSEN, P. A., DONALDSON, M. G., MALLINSON, A., RIDDELL, L., KRUSE, K., PRIOR, J. C. & FLICKER, L. 2002. Community-based exercise program reduces risk factors for falls in 65- to 75-year-old women with osteoporosis: Randomised controlled trial. *Canadian Medical Association Journal,* 167, 997-1004.

CASPERSEN, C. J., POWELL, K. E. & CHRISTENSON, G. 1985. Physical activity, exercise and physical fitness: definitions and distinctions for health-related research. *Public Health Reports,* 100, 126-131.

CHAN, B. K. S., MARSHALL, L. M., WINTERS, K. M., FAULKNER, K. A., SCHWARTZ, A. V. & ORWOLL, E. S. 2007. Incident fall risk and physical activity and physical performance among older men: The osteoporotic fractures in men study. *American Journal of Epidemiology,* 165, 696-703.

CHANDLER, J. M., DUNCAN, P. W., SANDERS, L. & STUDENSKI, S. 1996. The fear of falling syndrome: Relationship to falls, physical performance, and activities of daily living in frail older persons. *Topics in Geriatric Rehabilitation,* 11, 55-63.

CHANG, J. T., MORTON, S. C., RUBENSTEIN, L. Z., MOJICA, W. A., MAGLIONE, M., SUTTORP, M. J., ROTH, E. A. & SHEKELLE, P. G. 2004. Interventions for the prevention of falls in older adults: systematic review and meta-analysis of randomised clinical trials. *British Medical Journal,* 328, 680-683.

CHARETTE, S. L., MCEVOY, L., PYKA, G., SNOW-HARTER, C., GUIDO, D., WISWELL, R. A. & MARCUS, R. 1991. Muscle hypertrophy response to resistance training in older women. *Journal of Applied Physiology,* 70, 1912-1916.

CHEADLE, A. 2006. The Effect of Season on Physical Activity Among Older Adults in King County, Washington. *Journal of Physical Activity and Health,* 3, 304-313.

CHIANG, J. H. & WU, G. 1997. The influence of foam surfaces on biomechanical variables contributing to postural control. *Gait and Posture,* 5, 239-245.

CHODZKO-ZAJKO, W. J., PROCTOR, D. N., FIATARONE SINGH, M. A., MINSON, C. T., NIGG, C. R., SALEM, G. J. & SKINNER, J. S. 2009. Exercise and Physical Activity for Older Adults. *Medicine and Science in Sports and Exercise,* 41, 1510-1530.

CLEMSON, L., MACKENZIE, L., BALLINGER, C., CLOSE, J. C. & CUMMING, R. G. 2008. Environmental interventions to prevent falls in community-dwelling older people: a meta-analysis of randomised trials. *Journal of Aging and Health,* 20, 954-971.

COHEN, J. 1969. *Statistical power analysis for the behavioural sciences.* New York, Academic Press.

COLBERT, L. H., MATTHEWS, C. E., HAVIGHURST, T. C., KIM, K. & SCHOELLER, D. A. 2011. Comparative Validity of Physical Activity Measures in Older Adults. *Medicine and Science in Sports and Exercise,* 43, 867-876.

CONDRON, J. E. & HILL, K. D. 2002. Reliability and validity of a dual-task force platform assessment of balance performance: Effect of age, balance impairment, and cognitive task. *Journal of the American Geriatrics Society,* 50, 157-162.

CORNILLEAU-PERES, V., SHABANA, N., DROULEZ, J., GOH, J. C. H., LEE, G. S. M. & CHEW, P. T. K. 2005. Measurement of the visual contribution to postural steadiness from the COP movement: Methodology and reliability. *Gait and Posture,* 22, 96-106.

CORSINOVI, L., BO, M., RICAUDA AIMONINO, N., MARINELLO, R., GARIGLIO, F., MARCHETTO, C., GASTALDI, L., FISSORE, L., ZANOCCHI, M. & MOLASCHI, M. 2009. Predictors of falls and hospitalization outcomes in elderly patients admitted to an acute geriatric unit. *Archives Gerontology and Geriatrics,* 49, 142-145.

CRESS, M., BUCHNER, D., QUESTAD, K., ESSELMAN, P., DELATEUR, B. & SCHWARTZ, R. 1999. Exercise: effects on physical functional performance in independent older adults. *Journals of Gerontology. Series A, Biological Sciences and Medical Sciences,* 54, M242-M248.

CROSSMAN, A. & NEARY, D. 2005. *Neuroanatomy,* Manchester, Elsevier.

CSUKA, M. & MCCARTY, D. 1985. Simple method for measurement of lower extremity muscle strength. *The American Journal of Medicine,* 78, 77-81.

CURRIE, J. L. & DEVELIN, E. 2002. Stroll your way to well-being: a survey of the perceived benefits, barriers, community support and stigma associated with pram walking groups designed for new mothers, Sydney, Australia. *Health Care Women International,* 23, 882–893.

DALTROY, L. H., LARSON, M. G., EATON, H. M., PHILLIPS, C. B. & LIANG, M. H. 1999. Discrepancies between self-reported and observed physical function in the elderly: the influence of response shift and other factors. *Social Science & Medicine,* 48, 1549-1561.

DAVIDSON, B. S., MADIGAN, M. L., SOUTHWARD, S. C. & NUSSBAUM, M. A. 2011. Neural control of posture during small magnitude perturbations: effects of aging and localized muscle fatigue. *IEEE Transactions on Biomedical Engineering,* 58, 1546-1554.

DAVIS, J. C., MARRA, C. A., ROBERTSON, M. C., KHAN, K. M., NAJAFZADEH, M., ASHE, M. C. & LIU-AMBROSE, T. 2011. Economic evaluation of dose-response resistance training in older women: A cost-effectiveness and cost-utility analysis. *Osteoporosis International,* 22, 1355-1366.

DAY, L., FILDES, B., GORDON, I., FITZHARRIS, M., FLAMER, H. & LORD, S. 2002. Randomised factorial trial of falls prevention among older people living in their own homes. *British Medical Journal,* 325, 128-131.

DE BREUCKER, S., NKODO MEKONGO, Y. P., IBEBEKE, B. & PEPERSACK, T. 2007. Falls of older individuals: Medical assessment. *Les chutes du patient âgé: Aspects médicaux,* 28, 177-182.

DE GROOT, G. C. L. & FAGERSTROM, L. 2011. Older adults' motivating factors and barriers to exercise to prevent falls. *Scandinavian Journal of Occupational Therapy,* 18, 153-160.

DEAN, C. M., RICHARDS, C. L. & MALOUIN, F. 2000. Task-related circuit training improves performance of locomotor tasks in chronic stroke: A randomised, controlled pilot trial. *Archives of Physical Medicine and Rehabilitation,* 81, 409-417.

DEANDREA, S., LUCENTEFORTE, E., BRAVI, F., FOSCHI, R., LA VECCHIA, C. & NEGRI, E. 2010. Risk factors for falls in community-dwelling older people: A systematic review and meta-analysis. *Epidemiology,* 21, 658-668.

DECULLIER, E., COURIS, C. M., BEAUCHET, O., ZAMORA, A., ANNWEILER, C., DARGENT-MOLINA, P. & SCHOTT, A. M. 2010. Falls' and fallers' profiles. *Journal of Nutrition Health and Aging,* 14, 602-608.

DHESI, J., JACKSON, S., BEARNE, L., MONIZ, C., HURLEY, M., SWIFT, C. & ALLAIN, T. 2004. Vitamin D supplementation improves neuromuscular function in older people who fall. *Age and Aging,* 33, 589-595.

DHESI, J. K., BEARNE, L. M., MONIZ, C., HURLEY, M. V., JACKSON, S. H. D., SWIFT, C. G. & ALLAIN, T. J. 2002. Neuromuscular and psychomotor function in elderly subjects who fall and the relationship with vitamin D status. *Journal of Bone and Mineral Research,* 17, 891-897.

DI BREZZO, R. & FORT, I. L. 1987. Strength Norms for the Knee in Women 25 Years and Older. *The Journal of Strength & Conditioning Research,* 1, 45-47.

DI FABIO, R. P., GREANY, J. F., EMASITHI, A. & WYMAN, J. F. 2002. Eye-head coordination during postural perturbation as a predictor of falls in community-dwelling elderly women. *Archives of Physical Medicine and Rehabilitation,* 83, 942-951.

DIRKS-NAYLOR, A. J. & LENNON-EDWARDS, S. 2011. The effects of vitamin D on skeletal muscle function and cellular signaling. *Journal of Steroid Biochemistry and Molecular Biology,* 125, 159-168.

DITE, W. & TEMPLE, V. A. 2002a. A clinical test of stepping and change of direction to identify multiple falling older adults. *Archives of Physical Medicine and Rehabilitation,* 83, 1566-1571.

DITE, W. & TEMPLE, V. A. 2002b. Development of a clinical measure of turning for older adults. *American Journal of Physical Medicine and Rehabilitation,* 81, 857-66.

DODD, K., TAYLOR, N. & BRADLEY, S. 2004. Strength training for older people. *In:* MORRIS, M. & SCHOO, A. (eds.) *Optimizing Exercise and Physical Activity in Older People.* Sydney, Butterworth Heinemann.

DOLINIS, J., HARRISON, J. E. & ANDREWS, G. R. 1997. Factors associated with falling in older Adelaide residents. *Australian and New Zealand Journal of Public Health,* 21, 462-468.

DOWDY, J. C., SAYRE, R. M. & HOLICK, M. F. 2010. Holick's rule and vitamin D from sunlight. *Journal of Steroid Biochemistry and Molecular Biology,* 121, 328-330.

DUNCAN, P., WEINER, D., CHANDLER, J. & STUDENSKI, S. 1990. Functional Reach: A New Clinical Measure of Balance. *Journal of Gerontology,* 45, M192-M197.

EGERTON, T., BRAUER, S. G. & CRESSWELL, A. G. 2009. The immediate effect of physical activity on standing balance in healthy and balance-impaired older people. *Australasian Journal on Ageing,* 28, 93-96.

EGERTON, T., BRAUER, S. G. & CRESSWELL, A. G. 2010. Dynamic postural stability is not impaired by moderate-intensity physical activity in healthy or balance-impaired older people. *Human Movement Science,* 29, 1011-1022.

EL HABER, N., HILL, K. D., CASSANO, A. M., PATON, L. M., MACINNIS, R. J., CUI, J. S., HOPPER, J. L. & WARK, J. D. 2006. Genetic and environmental influences on variation in balance performance among female twin pairs aged 21-82 years. *American Journal of Epidemiology,* 164, 246-256.

ERA, P., SAINIO, P., KOSKINEN, S., HAAVISTO, P., VAARA, M. & AROMAA, A. 2006. Postural balance in a random sample of 7,979 subjects aged 30 years and over. *Gerontology,* 52, 204-213.

FAHLMAN, M., MORGAN, A., MCNEVIN, N., TOPP, R. & BOARDLEY, D. 2007. Combination training and resistance training as effective interventions to improve functioning in elders. *Journal of Aging and Physical Activity,* 15, 195-205.

FAHLMAN, M. M., MCNEVIN, N., BOARDLEY, D., MORGAN, A. & TOPP, R. 2011. Effects of Resistance Training on Functional Ability in Elderly Individuals. *American Journal of Health Promotion,* 25, 237-243.

FAULKNER, K. A., CAULEY, J. A., ROTH, S. M., KAMMERER, C., STONE, K., HILLIER, T. A., ENSRUD, K. E., HOCHBERG, M., NEVITT, M. C. & ZMUDA, J. M. 2010. Familial resemblance and shared latent familial variance in recurrent fall risk in older women. *Journal of Applied Physiology,* 108, 1142-1147.

FEIRING, D., ELLENBECKER, T. & DERSCHEID, G. 1990. Test-retest reliability of the biodex isokinetic dynamometer. *Journal of Orthopedic Sports Physical Therapy,* 11, 298-300.

FIATARONE, M. A., O'NEILL, E. F., RYAN, N. D., CLEMENTS, K. M., SOLARES, G. R., NELSON, M. E., ROBERTS, S. B., KEHAYIAS, J. J., LIPSITZ, L. A. & EVANS, W. J. 1994. Exercise training and nutritional supplementation for physical frailty in very elderly people. *New England Journal of Medicine,* 330, 1769-1775.

FLICKER, L., MACINNIS, R. J., STEIN, M. S., SCHERER, S. C., MEAD, K. E., NOWSON, C. A., THOMAS, J., LOWNDES, C., HOPPER, J. L. & WARK, J. D. 2005. Should older people in residential care receive vitamin D to prevent falls? Results of a randomised trial. *Journal of the American Geriatrics Society,* 53, 1881-1888.

FOLEY, S. J., LORD, S. R., SRIKANTH, V., COOLEY, H. & JONES, G. 2006. Falls risk is associated with pain and dysfunction but not radiographic osteoarthritis in older adults: Tasmanian Older Adult Cohort study. *Osteoarthritis and Cartilage,* 14, 533-539.

FRANKEL, J. E., BEAN, J. F. & FRONTERA, W. R. 2006. Exercise in the Elderly: Research and Clinical Practice. *Clinics in Geriatric Medicine,* 22, 239-256.

FRZOVIC, D., MORRIS, M. E. & VOWELS, L. 2000. Clinical tests of standing balance: Performance of persons with multiple sclerosis. *Archives of Physical Medicine and Rehabilitation,* 81, 215-221.

GAUCHARD, G. C., GANGLOFF, P., JEANDEL, C. & PERRIN, P. P. 2003. Influence of regular proprioceptive and bioenergetic physical activities on balance control in elderly women. *Journal of Gerontology Serives A, Biological Sciences and Medical Sciences,* 58, M846-M850.

GILLESPIE, L., ROBERTSON, C., GILLESPIE, W., LAMB, S., GATES, S., CUMMING, R. & ROWE, B. 2009. Interventions for preventing falls in older people living in the community. *Cochrane Database of Systematic Reviews* CD000340.

GILLIE, O. 2010. Sunlight robbery: A critique of public health policy on vitamin D in the UK. *Molecular Nutrition and Food Research,* 54, 1148-1163.

GLUCK, T., WIENTJES, H. & RAI, G. S. 1996. An evaluation of risk factors for in-patient falls in acute and rehabilitation elderly care wards. *Gerontology,* 42, 104-107.

GOLDSPINK, G. 2007. Loss of muscle strength during aging studied at the gene level. *Rejuvenation Research,* 10, 397-405.

GRANACHER, U., GRUBER, M. & GOLLHOFER, A. 2009. Resistance training and neuromuscular performance in seniors. *International Journal of Sports Medicine,* 30, 652-657.

GREENE, B. R., ODONOVAN, A., ROMERO-ORTUNO, R., COGAN, L., SCANAILL, C. N. & KENNY, R. A. 2010. Quantitative falls risk assessment using the timed up and go test. *IEEE Transactions on Biomedical Engineering,* 57, 2918-2926.

GREGG, E. W., PEREIRA, M. A. & CASPERSEN, C. J. 2000. Physical activity, falls, and fractures among older adults: A review of the epidemiologic evidence. *Journal of the American Geriatrics Society,* 48, 883-893.

GIULI, C..PAPA, R.,MOCCHEGIANI, E. & MARCELLINI, F. 2012 Predictors of participation in physical activity for community-dwelling elderly Italians. *Archives of Gerontology and Geriatrics,* 54, 50-54.

HAINES, T., KUYS, S. S., MORRISON, G., CLARKE, J., BEW, P. & MCPHAIL, S. 2007. Development and validation of the balance outcome measure for elder rehabilitation. *Archives of Physical Medicine and Rehabilitation,* 88, 1614-1621.

HAKKINEN, K., ALEN, M., KALLINEN, M., NEWTON, R. U. & KRAEMER, W. J. 2000. Neuromuscular adaptation during prolonged strength training, detraining and re-strength-training in middle-aged and elderly people. *European Journal of Applied Physiology,* 83, 51-62.

HARAN, M. J., CAMERON, I. D., IVERS, R. Q., SIMPSON, J. M., LEE, B. B., TANZER, M., PORWAL, M., KWAN, M. M., SEVERINO, C. & LORD, S. R. 2010. Effect on falls of providing single lens distance vision glasses to multifocal glasses wearers: VISIBLE randomised controlled trial. *British Medical Journal,* 340, c2265.

HAUER, K., ROST, B., RÜTSCHLE, K., OPITZ, H., SPECHT, N., BÄRTSCH, P., OSTER, P. & SCHLIERF, G. 2001. Exercise training for rehabilitation and secondary prevention of falls in geriatric patients with a history of injurious falls. *Journal of the American Geriatrics Society,* 49, 10-20.

HEANEY, R. P. 2004. Functional indices of vitamin D status and ramifications of vitamin D deficiency. *American Journal of Clinical Nutrition,* 80, 1706S-1709S.

HEANEY, R. P. 2006. Barriers to optimizing vitamin D-3 intake for the elderly. *Journal of Nutrition,* 136, 1123-1125.

HENDRIE, H. C. 1998. Epidemiology of dementia and Alzheimer's disease. *American Journal of Geriatric Psychiatry,* 6, S3-S18.

HENWOOD, T. R., RIEK, S. & TAAFFE, D. R. 2008. Strength versus muscle power-specific resistance training in community-dwelling older adults. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 63, 83-91.

HENWOOD, T. R. & TAAFFE, D. R. 2006. Short-term resistance training and the older adult: the effect of varied programmes for the enhancement of muscle strength and functional performance. *Clinical Physiology and Functional Imaging,* 26, 305-313.

HESS, J. A. & WOOLLACOTT, M. 2005. Effect of high-intensity strength-training on functional measures of balance ability in balance-impaired older adults. *Journal of Manipulative and Physiological Therapeutics,* 28, 582-590.

HILL, K., BERNHARDT, J., MCGANN, A., MALTESE, D. & BERKOVITS, D. 1996a. A new test of Dynamic Standing Balance for Stroke Patients: Reliability, Validity and Comparison with healthy elderly. *Physiotherapy Canada,* 48, 257-262.

HILL, K. & MURRAY, M. Physical Activity and Falls Prevention *In:* MORRIS, M. & SCHOO, A. (eds.) 2004 *Optimizing Exercise and Physical Activity in Older People.* Sydney, Butterworth Heinemann.

HILL, K., SCHWARZ, J., FLICKER, L. & CARROLL, S. 1999. Falls among healthy, community-dwelling, older women: a prospective study of frequency, circumstances, consequences and prediction accuracy. *Australian and New Zealand Journal of Public Health,* 23, 41-48.

HILL, K. D., MOORE, K. J., DOREVITCH, M. I. & DAY, L. M. 2008. Effectiveness of falls clinics: An evaluation of outcomes and client adherence to recommended interventions. *Journal of the American Geriatrics Society,* 56, 600-608.

HILL, K. D., SCHWARZ, J. A., KALOGEROPOULOS, A. J. & GIBSON, S. J. 1996b. Fear of falling revisited. *Archives of Physical Medicine and Rehabilitation,* 77, 1025-1029.

HOLICK, M. F. 2004. Sunlight and vitamin D for bone health and prevention of autoimmune diseases, cancers, and cardiovascular disease. *The American Journal of Clinical Nutrition,* 80, 1678S-1688S.

HOLICK, M. F. 2007. Vitamin D deficiency. *New England Journal of Medicine,* 357, 266-281.

HOLLAND, G. J., TANAKA, K., SHIGEMATSU, R. & NAKAGAICHI, M. 2002. Flexibility and physical functions of older adults: A review. *Journal of Aging and Physical Activity,* 10, 169-206.

HOLVIALA, J. H. S., SALLINEN, J. M., KRAEMER, W. J., ALEN, M. J. & HAKKINEN, K. K. T. 2006. Effect's of strength training on muscle strength characteristics, functional capabilities, and balance in middle-aged and older women. *Journal of Strength and Conditioning Research,* 20, 336-344.

HORAK, F. B., WRISLEY, D. M. & FRANK, J. 2009. The Balance Evaluation Systems Test (BESTest) to differentiate balance deficits. *Physical Therapy,* 89, 484-498.

HORIKAWA, E., MATSUI, T., ARAI, H., SEKI, T., IWASAKI, K. & SASAKI, H. 2005. Risk of falls in Alzheimer's disease: A prospective study. *Internal Medicine,* 44, 717-721.

HOWE, T. E., ROCHESTER, L., JACKSON, A., BANKS, P. M. H. & BLAIR, V. A. 2007. Exercise for improving balance in older people. *Cochrane Database of Systematic Reviews*, CD004963.

HOWZE, E. H., SMITH, M. & DIGILIO, D. A. 1989. Factors affecting the adoption of exercise behavior among sedentary older adults. *Health Education Research,* 4, 173-180.

HUGHES, M. A., DUNCAN, P. W., ROSE, D. K., CHANDLER, J. M. & STUDENSKI, S. A. 1996. The relationship of postural sway to sensorimotor function, functional performance, and disability in the elderly. *Archives of Physical Medicine and Rehabilitation,* 77, 567-572.

HUMPEL, N., OWEN, N., IVERSON, D., LESLIE, E. & BAUMAN, A. 2004. Perceived environment attributes, residential location, and walking for particular purposes. *American Journal of Preventive Medicine* 26, 119-125

HUXHAM, P., GOLDIE, P. & PATLA, A. 2001. Theoretical considerations in balance assessment. *Australian Journal of Physiotherapy,* 47, 89-100.

IMPELLIZZERI, F. M., BIZZINI, M., RAMPININI, E., CEREDA, F. & MAFFIULETTI, N. A. 2008. Reliability of isokinetic strength imbalance ratios measured using the Cybex NORM dynamometer. *Clinical Physiology and Functional Imaging,* 28, 113-119.

IREZ, G. B., OZDEMIR, R. A., EVIN, R., IREZ, S. G. & KORKUSUZ, F. 2011. Integrating Pilates exercise into an exercise program for 65+year-old women to reduce falls. *Journal of Sports Science and Medicine,* 10, 105-111.

ISLES, R. C., LOW CHOY, N. L., STEER, M. & NITZ, J. C. 2004. Normal values of balance tests in women aged 20-80. *Journal of the American Geriatrics Society,* 52, 1367-1372.

JAGLAL, S. B., KREIGER, N. & DARLINGTON, G. A. 1995. Lifetime occupational physical activity and risk of hip fracture in women. *Annals of Epidemiology,* 5, 321-324.

JANET BARGER-LUX, M. & HEANEY, R. P. 2002. Effects of above average summer sun exposure on serum 25-hydroxyvitamin D and calcium absorption. *Journal of Clinical Endocrinology and Metabolism,* 87, 4952-4956.

JARNLO, G. & JOHANSSON, G. 1991. Balance training in 70 year old women. *Physiotherapy Theory and Practice,* 7, 121-125.

JENSEN, J. L., BROWN, L. A. & WOOLLACOTT, M. H. 2001. Compensatory stepping: The biomechanics of a preferred response among older adults. *Experimental Aging Research,* 27, 361-376.

JETTE, A. M., LACHMAN, M., GIORGETTI, M. M., ASSMANN, S. F., HARRIS, B. A., LEVENSON, C., WERNICK, M. & KREBS, D. 1999. Exercise - It's never too late: The Strong-for-Life program. *American Journal of Public Health,* 89, 66-72.

JIANG, Y. F., NAGASAKI, S. & KIMURA, H. 2006. A dynamic model of body sway control during upright stance in human. *Japanese Journal of Physical Fitness and Sports Medicine,* 55, 231-235.

JOHNSON, B. M., MIAO, M. & SADUN, A. A. 1987. Age-related decline of human optic-nerve axon populations *Age,* 10, 5-9.

JOHNSON, C. S. J., MYERS, A. M., SCHOLEY, L. M., CYARTO, E. V. & ECCLESTONE, N. A. 2003. Outcome evaluation of the Canadian Centre for Activity and Aging's Home Support Exercise Program for frail older adults. *Journal of Aging and Physical Activity,* 11, 408-424.

JOHNSON, E. G., LARSEN, A., OZAWA, H., WILSON, C. A. & KENNEDY, K. L. 2007. The effects of Pilates-based exercise on dynamic balance in healthy adults. *Journal of Bodywork and Movement Therapies,* 11, 238-242.

JUDGE, J. O., WHIPPLE, R. H. & WOLFSON, L. I. 1994. Effects of resistance and balance exercises on isokinetic strength in older persons. *Journal of the American Geriatrics Society,* 42, 937-946.

JURKIEWICZ, M. T., MARZOLINI, S. & OH, P. 2011. Adherence to a home-based exercise program for individuals after stroke. *Topics in Stroke Rehabilitation,* 18, 277-284.

KAESLER, D. S., MELLIFONT, R. B., KELLY, P. S. & TAAFFE, D. R. 2007. A novel balance exercise program for postural stability in older adults: A pilot study. *Journal of Bodywork & Movement Therapies,* 11, 37-43.

KALAPOTHARAKOS, V. I., MICHALOPOULOS, M., TOKMAKIDIS, S. P., GODOLIAS, G. & GOURGOULIS, V. 2005. Effects of a heavy and a moderate resistance training on functional performance in older adults. *Journal of Strength and Conditioning Research,* 19, 652-657.

KALLIN, K., SANDMAN, P. O. & KARLSSON, S. 2004. Drugs and falls in older people in geriatric care settings. *Aging Clinical and Experimental Research,* 16, 270-276.

KALYANI, R. R., STEIN, B., VALIYIL, R., MANNO, R., MAYNARD, J. W. & CREWS, D. C. 2010. Vitamin D treatment for the prevention of falls in older adults: systematic review and meta-analysis. *Journal of the American Geriatrics Society,* 58, 1299-1310.

KATALINIC, O. M., HARVEY, L. A. HERBERT, R. D., MOSELEY, A. M. LANNIN, N. A. & SCHURR, K. 2010. Stretch for the treatment and prevention of contractures. *Cochrane Database of Systematic Reviews*, CD007455.

KAUFMAN, D. W., KELLY, J. P., ROSENBERG, L., ANDERSON, T. E. & MITCHELL, A. A. 2002. Recent patterns of medication use in the ambulatory adult population of the United States: the Slone survey. *Journal of the American Medical Association,* 287, 337-344.

KAZMIERSKI, J., KOWMAN, M., BANACH, M., FENDLER, W., OKONSKI, P., BANYS, A., JASZEWSKI, R., RYSZ, J., MIKHAILIDIS, D. P., SOBOW, T. & KLOSZEWSKA, I. 2010. Incidence and predictors of delirium after cardiac surgery: Results from The IPDACS Study. *Journal of Psychosomatic Research,* 69, 179-185.

KELSEY, J. L., BERRY, S. D., PROCTER-GRAY, E., QUACH, L., NGUYEN, U., LI, W. J., KIEL, D. P., LIPSITZ, L. A. & HANNAN, M. T. 2010. Indoor and outdoor falls in older adults are different: the maintenance of balance, independent living, intellect, and zest in the elderly of Boston study. *Journal of the American Geriatrics Society,* 58, 2135-2141.

KENNY, R. A. M., RUBENSTEIN, L. Z., TINETTI, M. E., BREWER, K., CAMERON, K. A., CAPEZUTI, E. A., JOHN, D. P., LAMB, S., MARTIN, F., ROCKEY, P. H., SUTHER, M., PETERSON, E. W. 2011. Summary of the Updated American Geriatrics Society/British Geriatrics Society Clinical Practice Guideline for Prevention of Falls in Older Persons. *Journal of the American Geriatrics Society,* 59, 148-157.

KERBER, K. A., ISHIYAMA, G. P. & BALOH, R. W. 2006. A longitudinal study of oculomotor function in normal older people. *Neurobiology of Aging,* 27, 1346-1353.

KERRIGAN, D. C., LEE, L. W., NIETO, T. J., MARKMAN, J. D., COLLINS, J. J. & RILEY, P. O. 2000. Kinetic alterations independent of walking speed in elderly fallers. *Archives of Physical Medicine and Rehabilitation,* 81, 730-735.

KIM, H., YOSHIDA, H. & SUZUKI, T. 2011. The effects of multidimensional exercise on functional decline, urinary incontinence, and fear of falling in community-dwelling elderly women with multiple symptoms of geriatric syndrome: A randomised controlled and 6-month follow-up trial. *Archives of Gerontology and Geriatrics,* 52, 99-105.

KING, A. 2001. Interventions to promote physical activity by older adults. *The Journals of Gerontology Series A, Biological sciences,* 56A, 36-46.

KLEIN, B. E., KLEIN, R., LEE, K. E. & CRUICKSHANKS, K. J. 1998. Performance-based and self-assessed measures of visual function as related to history of falls, hip fractures, and measured gait time. The Beaver Dam Eye Study. *Ophthalmology,* 105, 160-164.

KLOUBEC, J. A. 2010. Pilates for improvement of muscle endurance, flexibility, balance, and posture. *Journal of Strength and Conditioning Research,* 24, 661-667.

KOEPSELL, T. D., WOLF, M. E., BUCHNER, D. M., KUKULL, W. A., LACROIX, A. Z., TENCER, A. F., FRANKENFELD, C. L., TAUTVYDAS, M. & LARSON, E. B. 2004. Footwear style and risk of falls in older adults. *Journal of the American Geriatrics Society,* 52, 1495-1501.

KOMAGATA, S. & NEWTON, R. A. 2003. The effectiveness of Tai Chi on improving balance in older adults: An evidence-based review. *Journal of Geriatric Physical Therapy,* 26, 9-16.

KOMESU, Y. M., ROGERS, R. G., SCHRADER, R. M. & LEWIS, C. 2009. Incidence and remission of urinary incontinence in a community-based population of women ≥ 50 years. *International Urogynecology Journal,* 20, 581-589.

KOOIJMAN, A. C. & CORNELISSEN, F. W. 2005. Better lighting to reduce falls and fracture? A comment on de Boer et al. (2004): Different aspects of visual impairment as risk factors for falls and fractures in older men and women. *Journal of Bone and Mineral Research,* 20, 2061-2062.

KREBS, D. E., JETTE, A. M. & ASSMANN, S. F. 1998. Moderate exercise improves gait stability in disabled elders. *Archives of Physical Medicine and Rehabilitation,* 79, 1489-1495.

KRUGER, J., BROWN, D. R., GALUSKA, D. A. & BUCHNER, D. 2004. Strength Training Among Adults Aged ≥ 65 Years - United States, 2001. *MMWR. Morbidity and Mortality Weekly Report,* 53, 25.

KUTNER, N., BARNHART, H., WOLF, S., MCNEELY, E. & XU, T. 1997. Self-report benefits of Tai Chi Practice by older adults. *Journal of Gerontology: Psychological Sciences,* 52B, 242-246.

LAFOREST, S., PELLETIER, A., GAUVIN, L., ROBITAILLE, Y., FOURNIER, M., CORRIVEAU, H. & FILIATRAULT, J. 2009. Impact of a community-based falls prevention program on maintenance of physical activity among older adults. *Journal of Aging and Health,* 21, 480-500.

LATASH, M., FERRERIA, S., WEICZOREK, S. & DUARTE, M. 2003. Movement sway: Changes in postural sway during voluntary shifts of the center of pressure. *Experimental Brain Research,* 150, 314-324.

LATHAM, N. K., ANDERSON, C. S., LEE, A., BENNETT, D. A., MOSELEY, A., CAMERON, I. D. & FITNESS COLLABORATIVE, G. 2003. A randomised, controlled trial of quadriceps resistance exercise and vitamin D in frail older people: The Frailty Interventions Trial in Elderly Subjects (FITNESS). *Journal of the American Geriatrics Society,* 51, 291-299.

LAZARO, M., GONZALEZ, A., LATORRE, G., FERNANDEZ, C. & RIBERA, J. M. 2011. Postural stability in the elderly: Fallers versus non-fallers. *European Geriatric Medicine,* 2, 1-5.

LE CLAIR, K. & RIACH, C. 1996. Postural stability measures: what to measure and for how long. *Clinical Biomechanics,* 11, 176-178.

LE, T. T. & KAPOULA, Z. 2008. Role of ocular convergence in the Romberg quotient. *Gait and Posture,* 27, 493-500.

LEGTERS, K. 2002. Fear of falling. *Physical Therapy,* 82, 264–272.

LELARD, T., DOUTRELLOT, P. L., DAVID, P. & AHMAIDI, S. 2010. Effects of a 12-week Tai Chi Chuan program versus a balance training program on postural control and walking ability in older people. *Archives Physical Medicine and Rehabilitation,* 91, 9-14.

LI, F., HARMER, P., FISHER, K., MCAULEY, E., CHAUMETON, N., ECKSTROM, E., ET AL. & WILSON, N. 1995. Tai Chi and fall reductions in older adults: a randomised controlled trial *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 60, 187-194.

LI, F., HARMER, P., FISHER, K. J., MCAULEY, E., CHAUMETON, N., ECKSTROM, E. & WILSON, N. L. 2005. Tai Chi and fall reductions in older adults: A randomised controlled trial. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 60, 187-194.

LI, K. Z. & LINDENBERGER, U. 2002. Relations between aging sensory/sensorimotor and cognitive functions. *Neuroscience and biobehavioural reviews,* 26, 777-783.

LIN, M. R., WOLF, S. L., HWANG, H. F., GONG, S. Y. & CHEN, C. Y. 2007. A randomised, controlled trial of fall prevention programs and quality of life in older fallers. *Journal of the American Geriatrics Society,* 55, 499-506.

LIU-AMBROSE, T., DONALDSON, M. G., AHAMED, Y., GRAF, P., COOK, W. L., CLOSE, J., LORD, S. R. & KHAN, K. M. 2008. Otago home-based strength and balance retraining improves executive functioning in older fallers: A randomised controlled trial. *Journal of the American Geriatrics Society,* 56, 1821-1830.

LIU-AMBROSE, T., KHAN, K. M., DONALDSON, M. G., ENG, J. J. & AL, E. 2006. Falls-related self-efficacy is independently associated with balance and mobility in older women with low bone mass. *The Journals of Gerontology,* 61A, 832-838.

LIU-AMBROSE, T., KHAN, K. M., ENG, J. J., JANSSEN, P. A., LORD, S. R. & MCKAY, H. A. 2004. Resistance and agility training reduce fall risk in women aged 75 to 85 with low bone mass: A 6-month randomised, controlled trial. *Journal of the American Geriatrics Society,* 52, 657-665.

LIU-AMBROSE, T., NAGAMATSU, L. S., GRAF, P., BEATTIE, B. L., ASHE, M. C. & HANDY, T. C. 2010. Resistance Training and Executive Functions A 12-Month Randomised Controlled Trial. *Archives of Internal Medicine,* 170, 170-178.

LIU, B. A., TOPPER, A. K., REEVES, R. A., GRYFE, C. & MAKI, B. E. 1995. Falls among older people: Relationship to medication use and orthostatic hypotension. *Journal of the American Geriatrics Society,* 43, 1141-1145.

LIU, C. J. & LATHAM, N. K. 2009. Progressive resistance strength training for improving physical function in older adults. *Cochrane Database Systematic Review*, CD002759.

LORD, S., SHERRINGTON, C., MENZ, H. & CLOSE, J. (eds.) 2007. *Falls in older people; risk factors and srategies for prevention,* New York, Cambridge Press.

LORD, S. R. 2004. Physiological assessment of risk of falling in older people. *Journal of Aging and Physical Activity,* 12, 363-364.

LORD, S. R. 2006. Visual risk factors for falls in older people. *Age and Ageing,* 35, ii42-ii45.

LORD, S. R., CASTELL, S., CORCORAN, J., DAYHEW, J., MATTERS, B., SHAN, A. & WILLIAMS, P. 2003a. The effect of group exercise on physical functioning and falls in frail older people living in retirement villages: A randomised, controlled trial. *Journal of the American Geriatrics Society,* 51, 1685-1692.

LORD, S. R. & DAYHEW, J. 2001. Visual risk factors for falls in older people. *Journal of the American Geriatrics Society,* 49, 508-515.

LORD, S. R., LLOYD, D. G. & LI, S. K. 1996. Sensori-motor function, gait patterns and falls in community-dwelling women. *Age and Ageing,* 25, 292-299 .

LORD, S. R., MENZ, H. B. & TIEDEMANN, A. 2003b. A physiological profile approach to falls risk assessment and prevention. *Physical Therapy,* 83, 237-252.

LORD, S. R., MURRAY, S. M., CHAPMAN, K., MUNRO, B. & TIEDEMANN, A. 2002. Sit-to-Stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people. *The Journals of Gerontology,* 57A, M539-M543.

LORD, S. R., SAMBROOK, P. N., GILBERT, C., KELLY, P. J., NGUYEN, T., WEBSTER, I. W. & EISMAN, J. A. 1994a. Postural stability, falls and fractures in the elderly: Results from the Dubbo Osteoporosis Epidemiology Study. *Medical Journal of Australia,* 160, 684-685+688.

LORD, S. R., TIEDEMANN, A., CHAPMAN, K., MUNRO, B., MURRAY, S. M. & SHERRINGTON, C. 2005. The Effect of an Individualized Fall Prevention Program on Fall Risk and Falls in Older People: A Randomised, Controlled Trial. *Journal of the American Geriatrics Society,* 53, 1296-1304.

LORD, S. R. & WARD, J. A. 1994. Age-associated differences in sensori-motor function and balance in community dwelling women. *Age and Ageing,* 23, 452-460.

LORD, S. R., WARD, J. A., WILLIAMS, P. & ANSTEY, K. J. 1993. An epidemiological study of falls in older community-dwelling women: The Randwick falls and fractures study. *Australian Journal of Public Health,* 17, 240-245.

LORD, S. R., WARD, J. A., WILLIAMS, P. & ANSTEY, K. J. 1994b. Physiological factors associated with falls in older community-dwelling women. *Journal of the American Geriatrics Society,* 42, 1110-1117.

LORD, S. R., WARD, J. A., WILLIAMS, P. & STRUDWICK, M. 1995. The effect of a 12-month exercise trial on balance, strength, and falls in older women: A randomised controlled trial. *Journal of the American Geriatrics Society,* 43, 1198-1206.

LUCHIES, C. W., WALLACE, D., PAZDUR, R., YOUNG, S. & DEYOUNG, A. J. 1999. Effects of age on balance assessment using voluntary and involuntary step tasks. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 54, M140-M144.

LUUKINEN, H., KOSKI, K. & KIVELÄ, S. L. 1996. The relationship between outdoor temperature and the frequency of falls among the elderly in Finland. *Journal of Epidemiology and Community Health,* 50, 107.

MACKEY, D. C. & ROBINOVITCH, S. N. 2006. Mechanisms underlying age-related differences in ability to recover balance with the ankle strategy. *Gait and Posture,* 23, 59-68.

MAEJIMA, H., SUNAHORI, H., OTANI, T., SAKAMOTO, N., YOSHIMURA, O. & TOBIMATSU, Y. 2009. Effect of long-term, community-based daily exercise on the ability to control the dynamic standing balance of Japanese elderly persons in relation to falls. *Nursing and Health Sciences,* 11, 128-134.

MAGAZINER, J., SIMONSICK, E. M., KASHNER, T. M., HEBEL, J. R. & KENZORA, J. E. 1990. Predictors of functional recovery one year following hospital discharge for hip fracture - a prospective study, *Journals of Gerontology,* 45, M101-M107.

MAKI, B., HOLIDAY, P. & TOPPER, A. 1994. A Prospective study of postural balance and risk of falling. *Journal of Gerontology,* 49, M72-M84 .

MAKI, B. E. & MCILROY, W. E. 1999. Control of compensatory stepping reactions: Age-related impairment and the potential for remedial intervention. *Physiotherapy Theory and Practice,* 15, 69-90.

MAKI, B. E. & MCILROY, W. E. 2006. Control of rapid limb movements for balance recovery: Age-related changes and implications for fall prevention. *Age and Ageing,* 35, ii12-ii18.

MARKS, R., FOLEY, P. A., JOLLEY, D., KNIGHT, K. R., HARRISON, J. & THOMPSON, S. C. 1995. The effect of regular sunscreen use on vitamin D levels in an Australian population: Results of a randomised controlled trial. *Archives of Dermatology,* 131, 415-421.

MARTINSON, B. C., SHERWOOD, N. E., CRAIN, A. L., HAYES, M. G., KING, A. C., PRONK, N. P. & O'CONNOR, P. J. 2010. Maintaining physical activity among older adults: 24-month outcomes of the Keep Active Minnesota randomised controlled trial. *Preventive Medicine,* 51, 37-44.

MASSION, J. & WOOLACOTT, M. (eds.) 1996. *Posture and equilibrium.,* London: Arnold.

MATTHEWS, C. E., FREEDSON, P. S., HEBERT, J. R., STANEK, E. J., MERRIAM, P. A., ROSAL, M. C., EBBELING, C. B. & OCKENE, I. S. 2001. Seasonal Variation in Household, Occupational, and Leisure Time Physical Activity: Longitudinal Analyses from the Seasonal Variation of Blood Cholesterol Study. *American Journal of Epidemiology,* 153, 172-183.

MAVER, S. L., DODD, K. & MENZ, H. 2011. Lower limb reaction time discriminates between multiple and single fallers. *Physiotherapy Theory and Practice,* 27, 329-336.

MAZZETTI, S., KRAMER, W., VOLEK, J., DUNCAN, N., RATAMESS, N., GÃMEZ, A., NEWTON, R., HÃKKINEN, K. & FLECK, S. 2000. The influence of direct supervision of resistance training on strength performance. *Medicine and Science in Sports and Exercise,* 32, 1175-1184.

MCCARTER-BAYER, A., BAYER, F. & HALL, K. 2005. Preventing falls in acute care: an innovative approach. *Journal of Gerontological Nursing,* 31, 25-33.

MCCLURE, R. J., TURNER, C., PEEL, N., SPINKS, A., EAKIN, E. & HUGHES, K. 2005. Population-based interventions for the prevention of fall-related injuries in older people. *Cochrane Database of Systematic Review* CD004441.

MCMURDO, M. E. T. & GASKELL, A. 1991. Dark adaptation and falls in the elderly. *Gerontology,* 37, 221-224.

MCMURDO, M. E. T., MOLE, P. A. & PATERSON, C. R. 1997. Controlled trial of weight bearing exercise in older women in relation to bone density and falls. *British Medical Journal,* 314, 569.

MCNEIL, C., DOHERTY, T., STASHUK, D. & RICE, C. 2005. Motor unit number estimates in the tibialis anterior muscle of young, old, and very old men. *Muscle and Nerve,* 31, 461-467.

MEANS, K. M., RODELL, D. E. & O'SULLIVAN, P. S. 2005. Balance, mobility, and falls among community-dwelling elderly persons - Effects of a rehabilitation exercise program. *American Journal of Physical Medicine and Rehabilitation,* 84, 238-250.

MEHER, I. & ODDSSON, L. I. E. 2004. The effect of a cognitive task on voluntary step execution in healthy elderly and young individuals. *Journal of the American Geriatrics Society,* 52, 1255-1262.

MELZER, I., KURZ, I. & ODDSSON, L. I. E. 2010. A retrospective analysis of balance control parameters in elderly fallers and non-fallers. *Clinical Biomechanics,* 25, 984-988.

MENZ, H. B., LORD, S. R. & MCINTOSH, A. S. 2001. Slip resistance of casual footwear: Implications for falls in older adults. *Gerontology,* 47, 145-149.

MENZ, H. B., MORRIS, M. E. & LORD, S. R. 2005. Foot and Ankle Characteristics Associated With Impaired Balance and Functional Ability in Older People. *The Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 60, 1546-1552.

MENZ, H. B., MORRIS, M. E. & LORD, S. R. 2006. Foot and ankle risk factors for falls in older people: A prospective study. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 61, 866-870.

MIRCHANDANI, S., AHARONOFF, G. B., HIEBERT, R., CAPLA, E. L., ZUCKERMAN, J. D. & KOVAL, K. J. 2005. The effects of weather and seasonality on hip fracture incidence in older adults. *Orthopedics,* 28, 149-155.

MISZKO, T. A., CRESS, M. E., SLADE, J. M., COVEY, C. J., AGRAWAL, S. K. & DOERR, C. E. 2003. Effect of strength and power training on physical function in community-dwelling older adults. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 58, 171-175.

MOCHIZUKI, L., DUARTE, M., AMADIO, A., ZATSIORSKY, V. & LATASH, M. 2006. Changes in postural sway and its fractions in conditions of postural instability. *Journal of Applied Biomechanics,* 22, 51-60.

MOLLER, J. 2003. Projected costs of fall related injury to older person due to demographic change in Australia. Commonwealth Department of Health and Ageing, Canberra.

MOREIRA-PFRIMER, L. D. F., PEDROSA, M. A. C., TEIXEIRA, L. & LAZARETTI-CASTRO, M. 2009. Treatment of vitamin D deficiency increases lower limb muscle strength in institutionalized older people independently of regular physical activity: a eandomised double-blind controlled trial. *Annals of Nutrition and Metabolism,* 54, 291-300.

MORELAND, J. D., RICHARDSON, J. A., GOLDSMITH, C. H. & CLASE, C. M. 2004. Muscle weakness and falls in older adults: A systematic review and meta-analysis. *Journal of the American Geriatrics Society,* 52, 1121-1129.

MORGAN, R. O., VIRNIG, B. A., DUQUE, M., ABDEL-MOTY, E. & DEVITO, C. A. 2004. Low-intensity exercise and reduction of the risk for falls among at-risk elders. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 59, 1062-1067.

MORITANI, T. & DEVRIES, H. A. 1979. Neural factors versus hypertrophy in the time course of muscle strength gain. *American Journal of Physical Medicine,* 58, 115-130.

MORRIS, M., IANSEK, R., SMITHSON, F. & HUXHAM, F. 2000. Postural instability in Parkinson's disease: A comparison with and without a concurrent task. *Gait and Posture,* 12, 205-216.

MUIR, S. W., BERG, K., CHESWORTH, B., KLAR, N. & SPEECHLEY, M. 2011. Application of a fall screening algorithm stratified fall risk but missed preventive opportunities in community-dwelling older adults: A prospective study. *Journal of Geriatric Physical Therapy*, 33, 165-172.

MUIR, S. W. & MONTERO-ODASSO, M. 2011. Effect of vitamin D supplementation on muscle strength, gait and balance in older adults: A systematic review and meta-analysis, *Journal of the American Geriatrics Society,* 59, 2291-2300.

MÜLLER-RIEMENSCHNEIDER, F., REINHOLD, T., NOCON, M. & WILLICH, S. N. 2008. Long-term effectiveness of interventions promoting physical activity: A systematic review. *Preventive Medicine,* 47, 354-368.

MURRAY, M. P., GARDNER, G. M., MOLLINGER, L. A. & SEPIC, S. B. 1980. Strength of isometric and isokinetic contractions. *Physical Therapy,* 60, 412-419.

NACHREINER, N. M., FINDORFF, M. J., WYMAN, J. F. & MCCARTHY, T. C. 2007. Circumstances and consequences of falls in community-dwelling older women. *Journal of Womens Health,* 16, 1437-1446.

NASHNER, L. & MCCOLLUM, G. 1985. The organization of human postural movements: a formal basis and experimental synthesis. *Behaviour and Brain Sciences,* 8, 135-172.

NASHNER, L. M. 1971. Model describiing vestibular detection of body sway Motion. *Acta Oto-Laryngologica,* 72, 429-436.

NELSON, M. E., FIATARONE, M. A., MORGANTI, C. M., TRICE, I., GREENBERG, R. A. & EVANS, W. J. 1994. Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures. A randomised controlled trial. *Journal of the American Medical Association,* 272, 1909-1914.

NEVITT, M. C., CUMMINGS, S. R. & HUDES, E. S. 1991. Risk factors for injurious falls: A prospective study. *Journals of Gerontology,* 46 M164-M170.

NEVITT, M. C., CUMMINGS, S. R., KIDD, S. & BLACK, D. 1989. Risk factors for recurrent nonsyncopal falls. A prospective study. *Journal of the American Medical Association,* 261, 2663-2668.

NICHOLS, J. F., HITZELBERGER, L. M., SHERMAN, J. G. & PATTERSON, P. 1995. Effects of resistence training on muscular strength and functional abilities of community-dwelling older adults. *Journal of Aging and Physical Activity,* 3, 238-250.

NITZ, J. C. & CHOY, N. L. 2004. The efficacy of a specific balance-strategy training programme for preventing falls among older people: a pilot randomised controlled trial. *Age and Ageing,* 33, 52-58.

NORVAL, M. & WULF, H. C. 2009. Does chronic sunscreen use reduce vitamin D production to insufficient levels? *British Journal of Dermatology,* 161, 732-736.

NOWSON, C. A. & MARGERISON, C. 2002. Vitamin D intake and vitamin D status of Australians. *Medical Journal of Australia,* 177, 149-152.

O'LOUGHLIN, J. L., BOIVIN, J. F., ROBITAILLE, Y. & SUISSA, S. 1994. Falls among the elderly: Distinguishing indoor and outdoor risk factors in Canada. *Journal of Epidemiology and Community Health,* 48, 488-489.

O'LOUGHLIN, J. L., ROBITAILLE, Y., BOIVIN, J. F. & SUISSA, S. 1993. Incidence of and risk factors for falls and injurious falls among the community-dwelling elderly. *American Journal of Epidemiology,* 137, 342-354.

OKUMIYA, K., MATSUBAYASHI, K., WADA, T., KIMURA, S., DOI, Y. & OZAWA, T. 1996. Effects of exercise on neurobehavioral function in community-dwelling older people more than 75 years of age. *Journal of the American Geriatrics Society,* 44, 569-572.

ORR, R. 2010. Contribution of muscle weakness to postural instability in the elderly: A systematic review. *European Journal of Physical and Rehabilitation Medicine,* 46, 183-220.

ORR, R., DE VOS, N. J., SINGH, N. A., ROSS, D. A., STAVRINOS, T. M. & FIATARONE-SINGH, M. A. 2006. Power training improves balance in healthy older adults. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 61, 78-85.

ORR, R., RAYMOND, J., AND FIATARONE, M. 2008. Efficacy of progressive resistance training on balance performance in older adults: A systematic review of randomised controlled trials. *Sports Medicine,* 38, 317-343.

OSWALD, A. E., PYE, S. R., O'NEILL, T. W., BUNN, D., GAFFNEY, K., MARSHALL, T., SILMAN, A. J. & SYMMONS, D. P. M. 2006. Prevalence and associated factors for falls in women with established inflammatory polyarthritis. *Journal of Rheumatology,* 33, 690-694.

PAJALA, S., ERA, P., KOSKENVUO, M., KAPRIO, J., TORMAKANGAS, T. & RANTANEN, T. 2008. Force platform balance measures as predictors of indoor and outdoor falls in community-dwelling women aged 63-76 years. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 63, 171-178.

PANEL ON PREVENTION OF FALLS IN OLDER PERSONS, 2011. Society clinical practice guideline for prevention of falls in older persons. *Journal of the American Geriatrics Society,* 59, 148-157.

PASCO, J. A., HENRY, M. J., KOTOWICZ, M. A., SANDERS, K. M., SEEMAN, E., PASCO, J. R., SCHNEIDER, H. G. & NICHOLSON, G. C. 2004. Seasonal periodicity of serum vitamin D and parathyroid hormone, bone resorption, and fractures: the Geelong osteoporosis study. *Journal of Bone and Mineral Research,* 19, 752-758.

PASCO, J. A., HENRY, M. J., NICHOLSON, G. C., SANDERS, K. M. & KOTOWICZ, M. A. 2001. Vitamin D status of women in the Geelong Osteoporosis Study: association with diet and casual exposure to sunlight. *Medical Journal of Australia,* 175, 401-405.

PATE, R. R., PRATT, M., BLAIR, S. N., HASKELL, W. L., MACERA, C. A., BOUCHARD, C., BUCHNER, D., ETTINGER, W., HEATH, G. W., KING, A. C., KRISKA, A., LEON, A. S., MARCUS, B. H., MORRIS, J., PAFFENBARGER, R. S., PATRICK, K., POLLOCK, M. L., RIPPE, J. M., SALLIS, J. & WILMORE, J. H. 1995. Physical activity and public health: a recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine *Journal of the American Medical Association,* 273, 402-407.

PATERSON, D. H., JONES, G. R. & RICE, C. L. 2007. Ageing and physical activity: evidence to develop exercise recommendations for older adults. *Applied Physiology Nutrition and Metabolism-Physiologie Appliquee Nutrition Et Metabolisme,* 32, S69-S108.

PATERSON, D. H. & WARBURTON, D. E. R. 2010. Physical activity and functional limitations in older adults: A systematic review related to Canada's Physical Activity Guidelines. *International Journal of Behavioral Nutrition and Physical Activity,* 7, 7-38.

PEETERS, G. M. E. E., VERWEIJ, L. M., VAN SCHOOR, N. M., PIJNAPPELS, M., PLUIJM, S. M. F., VISSER, M. & LIPS, P. 2010. Which types of activities are associated with risk of recurrent falling in older persons?

Journals of Gerontology Series A, Biological Sciences and Medical Sciences, 65, 743-750.

PETRELLA, R. J., LATTANZIO, P. J. & NELSON, M. G. 1997. Effect of age and activity on knee joint proprioception. *American Journal of Physical Medicine and Rehabilitation,* 76, 235-241.

PFEIFER, M., BEGEROW, B., MINNE, H., ABRAMS, C., NACHTIGALL, D. & HANSEN, C. 2000. Effects of Short-term Vitamin D and Calcium Supplementation on Body Sway and Secondary Hyperparathyroidism in Elderly Women. *Journal of Bone and Mineral Research,* 15, 1113-1118.

PFEIFER, M., BEGEROW, B., MINNE, H., SUPPAN, K., FAHRLEITNER-PAMMER, A. & DOBNIG, H. 2009. Effects of a long-term vitamin D and calcium supplementation on falls and parameters of muscle function in community-dwelling older individuals. *Osteoporosis International,* 20, 315-322.

PIVARNIK, J. M., REEVES, M. J. & RAFFERTY, A. P. 2003. Seasonal variation in adult leisure-time physical activity. / Variation saisonniere du temps d ' activite physique de loirsirs des adultes. *Medicine and Science in Sports and Exercise,* 35, 1004-1008.

PODSIADLO, D. & RICHARDSON, S. 1991. The timed 'Up and Go': A test of basic functional mobility for frail elderly persons. *Journal of the American Geriatrics Society,* 39, 142-148.

POWELL, L. E. & MYERS, A. M. 1995. The Activities-specific Balance Confidence (ABC) Scale. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,,* 50, M28-M34.

PROVINCE, M. A., HADLEY, E. C., HORNBROOK, M. C., LIPSITZ, L. A., MULROW, C. D., ORY, M. G., SATTIN, R. W., TINETTI, M. E. & WOLF, S. L. 1995. The effects of exercise on falls in elderly patients - a preplanned meta-analysis of the FICSIT trials. *Journal of the American Medical Association,* 273, 1341-1347.

RAICHE, M., HEBERT, R., PRINCE, F. & CORRIVEAU, H. 2000. Screening older adults at risk of falling with the Tinetti balance scale. *Lancet,* 356, 1001-1002.

RAMSBOTTOM, R., AMBLER, A., POTTER, J., JORDAN, B., NEVILL, A. & WILLIAMS, C. 2004. The effect of 6 months training on leg power, balance, and functional mobility of independently living adults over 70 years old. *Journal of Aging and Physical Activity,* 12, 497-510.

RAND, D., MILLER, W. C., YIU, J. & ENG, J. J. 2011. Interventions for addressing low balance confidence in older adults: A systematic review and meta-analysis. *Age and Ageing,* 40, 297-306.

RAYMAKERS, J., SAMSON, M. AND VERHAAR, H. 2005. The assessment of body sway and the choice of the stability parameter(s). *Gait and Posture,* 21, 48-58.

REEDER, B. A., CHAD, K. E., HARRISON, E. L., ASHWORTH, N. L., SHEPPARD, M. S., FISHER, K. L., BRUNER, B. G., QUINN, B. G., PAHWA, P. & HOSSAIN, M. A. 2008. Saskatoon in motion: Class-versus home-based exercise intervention for older adults with chronic health conditions. *Journal of Physical Activity and Health,* 5, 74-87.

REFSHAUGE, K. M. & FITZPATRICK, R. C. 1995. Perception of movement at the human ankle: Effects of leg position. *Journal of Physiology,* 488, 243-248.

REINSCH, S., MACRAE, P., LACHENBRUCH, P. A. & TOBIS, J. S. 1992. Attempts to prevent falls and injury: a prospective community study. *Gerontologist,* 32, 450-456.

REJESKI, W. & MIHALKO, S. 2001. Physical Activity and Quality of Life in Older Adults. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 56, 23-35.

RHODES, R. E., MARTIN, A. D., TAUNTON, J. E., RHODES, E. C., DONNELLY, M. & ELLIOT, J. 1999. Factors associated with exercise adherence among older adults. An individual perspective. *Sports Medicine,* 28, 397-411.

ROBERTSON, M., CAMPBELL, A., GARDNER, M. & DEVLIN, N. 2001. Effectiveness and economic evaluation of a nurse delivered home exercise programme to prevent falls. Randomised controlled trial. *British Medical Journal,* 322, 697-701.

ROBERTSON, M., CAMPBELL, A., GARDNER, M. & DEVLIN, N. 2002. Preventing injuries in older people by preventing falls: a meta-analysis of individual-level data. *Journal of American Geriatric Society,* 50, 905-911.

ROOKS, D. S., KIEL, D. P., PARSONS, C. & HAYES, W. C. 1997. Self-paced resistance training and walking exercise in community-dwelling older adults: Effects on neuromotor performance. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 52, M161-M168.

ROSE, D. 2008. Preventing falls among older adults: No "one size suits all" intervention strategy. *Journal of Rehabilitation Research and Development,* 45, 1153-1166.

ROSEN, C. J. 2011. Vitamin D Insufficiency. *New England Journal of Medicine,* 364, 248-254.

RUBENSTEIN, L. 2006. Falls in older people: Epidemiology, risk factors and strategies for prevention. *Age and Ageing,* 35-S2, ii37-ii41.

RUBENSTEIN, L. & JOSEPHSON, K. 2006. Falls and Their Prevention in Elderly People: What Does the Evidence Show? *Medical Clinics of North America,* 90, 807-824.

RUGELJ, D. 2010. The effect of functional balance training in frail nursing home residents. *Archives of Gerontology and Geriatrics,* 50, 192-197.

RUHE, A., FEJER, R. & WALKER, B. 2010. The test-retest reliability of centre of pressure measures in bipedal static task conditions--a systematic review of the literature. *Gait and Posture,* 32, 436-445.

RUSSELL, M. A., HILL, K. D., DAY, L. M., BLACKBERRY, I., GURRIN, L. C. & DHARMAGE, S. C. 2009. Development of the Falls Risk for Older People in the Community (FROP-Com) screening tool. *Age and Ageing,* 38, 40-46.

SABAPATHY, N. M., MINAHAN, C. L., TURNER, G. T. & BROADLEY, S. A. 2011. Comparing endurance- and resistance-exercise training in people with multiple sclerosis: a randomised pilot study. *Clinical Rehabilitation,* 25, 14-24.

SALEM, G. J., SKINNER, J. S., CHODZKO-ZAJKO, W. J., PROCTOR, D. N., FIATARONE SINGH, M. A., MINSON, C. T. & NIGG, C. R. 2009. Exercise and physical activity for older adults. *Medicine and Science in Sports and Exercise,* 41, 1510-1530.

SALMAN, K., STOTT, V., ALHABIAN, O., STROUD, M. & STILGOE, S. 2008. Vitamin D: a review. *Australian Family Physician,* 37, 1002-1005.

SALMON, J., CRAWFORD, D., OWEN, N., BAUMAN, A. & SALLIS, J. F. 2003. Physical activity and sedentary behavior: A population-based study of barriers, enjoyment, and preference. *Health Psychology,* 22, 178-188.

SANDERS, K., STUART, A., WILLIAMSON, E., SIMPSON, J., KOTOWICZ, M. & NICHOLSON, G. 2011. The Efficacy of High-Dose Oral Vitman D3 admistered once a year: a randomised, double-blind, placebo-controlled trial (Vital D Study) for fall and fractures in older women. *Osteoporosis International,* 22, 104-105.

SAYERS, S. P., BEAN, J., CUOCO, A., LEBRASSEUR, N. K., JETTE, A. & FIELDING, R. A. 2003. Changes in function and disability after resistance training: Does velocity matter? A pilot study. *American Journal of Physical Medicine & Rehabilitation,* 82, 605-613.

SCHLICHT, J., CAMAIONE, D. N. & OWEN, S. V. 2001. Effect of intense strength training on standing balance, walking speed, and Sit-to-Stand performance in older adults. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 56, M281-M286.

SCHMID, A. A., VAN PUYMBROECK, M. & KOCEJA, D. M. 2010. Effect of a 12-week yoga intervention on fear of falling and balance in older adults: a pilot study. *Archives of Physical Medicine and Rehabilitation,* 91, 576-583.

SCHOT, P., KNUTZEN, K., POOLE, S. & MROTEK, L. 2003. Sit-to-Stand performance of older adults following strength training. *Research Quarterly for Exercise and Sport,* 74, 1-6.

SCOTT, D., BLIZZARD, L., FELL, J., DING, C., WINZENBERG, T. & JONES, G. 2010. A prospective study of the associations between 25-hydroxy-vitamin D, sarcopenia progression and physical activity in older adults. *Clinical Endocrinology,* 73, 581-587.

SCRAGG, R. & CAMARGO, C. 2008. Frequency of leisure-time physical activity and serum 25-Hydroxyvitamin D levels in the US population: results from the third national health and nutrition examination survey. *American Journal of Epidemiology,* 168, 577-586.

SEIDLER, R. D., BERNARD, J. A., BURUTOLU, T. B., FLING, B. W., GORDON, M. T., GWIN, J. T., KWAK, Y. & LIPPS, D. B. 2010. Motor control and aging: Links to age-related brain structural, functional, and biochemical effects. *Neuroscience and Biobehavioral Reviews,* 34, 721-733.

SELIG, S. E., CAREY, M. F., MENZIES, D. G., PATTERSON, J., GEERLING, R. H., WILLIAMS, A. D., BAMROONGSUK, V., TOIA, D., KRUM, H. & HARE, D. L. 2004. Moderate-intensity resistance exercise training in patients with chronic heart failure improves strength, endurance, heart rate variability, and forearm blood flow. *Journal of Cardiac Failure,* 10, 21-30.

SERRADOR, J. M., LIPSITZ, L. A., GOPALAKRISHNAN, G. S., BLACK, F. O. & WOOD, S. J. 2009. Loss of otolith function with age is associated with increased postural sway measures. *Neuroscience Letters,* 465, 10-15.

SHAFFER, S. W. & HARRISON, A. L. 2007. Aging of the somatosensory system: A translational perspective. *Physical Therapy,* 87, 193-207.

SHAW, F. E. 2003. Falls in older people with dementia. *Geriatrics and Aging,* 6, 37-40.

SHERRINGTON, C. & LORD, S. 2005. Reliability of simple portable tests of physical performance in older people after hip fracture. *Clinical Rehabilitation,* 19, 496-504.

SHERRINGTON, C. & LORD, S. R. 1997. Home exercise to improve strength and walking velocity after hip fracture: A randomised controlled trial. *Archives of Physical Medicine and Rehabilitation,* 78, 208-212.

SHERRINGTON, C., LORD, S. R. & FINCH, C. F. 2004. Physical activity interventions to prevent falls among older people: update of the evidence. *Journal of Science and Medicine in sport / Sports Medicine Australia,* 7, 43-51.

SHERRINGTON, C., WHITNEY, J. C., LORD, S. R., HERBERT, R. D., CUMMING, R. G. & CLOSE, J. C. T. 2008. Effective exercise for the prevention of falls: A systematic review and meta-analysis. *Journal of the American Geriatrics Society,* 56, 2234-2243.

SHI, C. M., WANG, D. X., CHEN, K. S. & GU, X. E. 2010. Incidence and risk factors of delirium in critically ill patients after non-cardiac surgery. *Chinese Medical Journal,* 123, 993-999.

SHIGEMATSU, R., CHANG, M. L., YABUSHITA, N., SAKAI, T., NAKAGAICHI, M., NHO, H. & TANAKA, K. 2002. Dance-based aerobic exercise may improve indices of falling risk in older women. *Age and Ageing,* 31, 261-266.

SHINJI, S., SHIGERU, M., RYUSEI, U., MITSURU, M. & SHIGEHIRO, K. 2007. Adherence to a home-based exercise program and incidence of cardiovascular disease in type 2 diabetes patients. *International Journal of Sports Medicine,* 28, 877-879.

SHUMWAY-COOK, A., BRAUER, S. & WOOLLACOTT, M. 2000. Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. *Physical Therapy,* 80, 896-903

SHUMWAY-COOK, A. & HORAK, F. B. 1986. Assessing the influence of sensory interaction on balance: suggestion from the field. *Physical Therapy,* 66, 1548-1550.

SHUMWAY-COOK, A., SILVER, I., LEMIER, M., YORK, S., CUMMINGS, P. & KOEPSELL, T. 2007. Effectiveness of a community-based multifactorial intervention on falls and fall risk factors in community-living older adults: A randomised, controlled trial. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 62, 1420-1427.

SIMONS, R. & ANDEL, R. 2006. The effects of resistance training and walking on functional fitness in advanced old age. *Journal of Aging and Health,* 18, 91-105.

SIMS, J., HILL, K., HUNT, S. & HARALAMBOUS, B. 2010. Physical activity recommendations for older Australians. *Australasian Journal on Ageing,* 29, 81-87.

SINGH, N. A., CLEMENTS, K. M. & FIATARONE, M. A. 1997. A randomised controlled trial of progressive resistance training in depressed elders. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 52, M27-M35.

SKELTON, D. 2001. Effects of physical activity on postural stability. *Age Ageing,* 30, 33-39.

SKELTON, D., DINAN, S., CAMPBELL, M. & RUTHERFORD, O. 2005. Tailored group exercise (Falls Management Exercise-FaME) reduces falls in community-dwelling older frequent fallers (an RCT). *Age and Ageing,* 34, 636-639.

SKELTON, D. A. & MCLAUGHLIN, A. W. 1996. Training functional ability in old age. *Physiotherapy,* 82, 159-167.

SKELTON, D. A., YOUNG, A., GREIG, C. A. & MALBUT, K. E. 1995. Effects of Resistance Training on Strength, Power, and Selected Functional Abilities of Women Aged 75 and Older. *Journal of the American Geriatrics Society,* 43, 1081-1087.

SKINNER, H. B., BARRACK, R. L. & COOK, S. D. 1984. Age related decline in proprioception. *Clinical Orthopaedics and Related Research,* 184, 208-211.

SMITH, S. T., SHERRINGTON, C., STUDENSKI, S., SCHOENE, D. & LORD, S. R. 2011. A novel Dance Dance Revolution (DDR) system for in-home training of stepping ability: basic parameters of system use by older adults. *British Journal of Sports Medicine,* 45, 441-445.

SOUSA, N. & SAMPAIO, J. 2005. Effects of progressive strength training on the performance of the functional reach test and the timed up and go test of an elderly population from the rural north of Portugal. *American Journal of Human Biology,* 17, 746-751.

SPEECHLEY, M. 2011. Unintentional falls in older adults: A methodological historical review. *Canadian Journal on Aging/Revue canadienne du vieillissement,* 30, 21-32.

SPEERS, R. A., ASHTON-MILLER, J. A., SCHULTZ, A. B. & ALEXANDER, N. B. 1998. Age differences in abilities to perform tandem stand and walk tasks of graded difficulty. *Gait and Posture,* 7, 207-213.

SPENNEWYN, K. C. 2008. Strength outcomes in fixed versus free-form resistance equipment. *Journal of Strength and Conditioning Research,* 22, 75-81.

SPIEGEL, K., STRATTON, J., BURKE, JR, GLENDINNING, D. & ENOKA, R. 1996. The influence of age on the assessment of motor unit activation in a human hand muscle. *Experimental Physiology,* 81, 805-819.

SPINK, M. J., FOTOOHABADI, M. R., WEE, E., HILL, K. D., LORD, S. R. & MENZ, H. B. 2011a. Foot and Ankle Strength, Range of Motion, Posture, and Deformity Are Associated With Balance and Functional Ability in Older Adults. *Archives of Physical Medicine and Rehabilitation,* 92, 68-75.

SPINK, M. J., MENZ, H. B., FOTOOHABADI, M. R., WEE, E., LANDORF, K. B., HILL, K. D. & LORD, S. R. 2011b. Effectiveness of a multifaceted podiatry intervention to prevent falls in community dwelling older people with disabling foot pain: randomised controlled trial. *British Medical Journal,* 342, d3411.

ST GEORGE, R. J., FITZPATRICK, R. C., ROGERS, M. W. & LORD, S. R. 2007. Choice stepping response and transfer times: Effects of age, fall risk, and secondary tasks. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 62, 537-542.

STEFAN, T., HACKER, T. & MOLLINGER, L. 2002. Age and gender-related test performance in community-dwelling elderly people: Six-minute walk test, berg balance scale, timed up and go test, and gait speeds. *Physical Therapy,* 82, 128-137.

STEL, V. S., SMIT, J. H., PLUIJM, S. M. F. & LIPS, P. 2003. Balance and mobility performance as treatable risk factors for recurrent falling in older persons. *Journal of Clinical Epidemiology,* 56, 659-668.

STELMACH, G. E., PHILLIPS, J., DIFABIO, R. P. & TEASDALE, N. 1989. Age, Functional Postural Reflexes, and Voluntary Sway. *Journals of Gerontology,* 44, B100-B106.

STELMACH, G. E. & WORRINGHAM, C. J. 1985. Sensorimotor deficits related to postural stability. Implications for falling in the elderly. *Clinics in Geriatric Medicine,* 1, 679-694.

STEVENS, J. & SOLOGOW, E. 2005. Gender differences for non-fatal unintentional fall related injuries among older adults. *Injury Prevention,* 11, 115-119.

STEWART, A. L., MILLS, K. M., KING, A. C., HASKELL, W. L., GILLIS, D. & RITTER, P. L. 2001. CHAMPS physical activity questionnaire for older adults: outcomes for interventions. *Medicine and Science in Sports and Exercise,* 33, 1126-1141.

STOCKTON, K., MENGERSEN, K., PARATZ, J., KANDIAH, D. & BENNELL, K. 2011. Effect of vitamin D supplementation on muscle strength: A systematic review and meta-analysis. *Osteoporosis International,* 22, 859-871.

STRAWBRIDGE, W. J., DELEGER, S., ROBERTS, R. E. & KAPLAN, G. A. 2002. Physical Activity Reduces the Risk of Subsequent Depression for Older Adults. *American Journal of Epidemiology,* 156, 328-334.

STUDENSKI, S., PERERA, S., HILE, E., KELLER, V., SPADOLA-BOGARD, J. & GARCIA, J. 2010. Interactive video dance games for healthy older adults. *Journal of Nutrition and Healthy Aging,* 14, 850-852.

SUMUKADAS, D., WITHAM, M., STRUTHERS, A. & MCMURDO, M. 2009. Day length and weather conditions profoundly affect physical activity levels in older functionally impaired people. *Journal of Epidemiology and Community Health,* 63, 305-309.

SUTTANON, P., HILL, K., SAID, C. & DODD, K. 2010. Can balance exercise programmes improve balance and related physical performance measures in people with dementia? A systematic review. *European Review of Aging and Physical Activity,* 7, 13-25.

TAAFFE, D. R., DURET, C., WHEELER, S. & MARCUS, R. 1999. Once-weekly resistance exercise improves muscle strength and neuromuscular performance in older adults. *Journal of the American Geriatrics Society,* 47, 1208-1214.

TAFFE, D. 2004. Declining muscle function in older people - repairing the deficits with exercise. *In:* MORRIS, M. A. & SCHOO, A (eds.) *Optimizing Exercise and physical activity in older people.* Sydney, Butterworth Heinemann.

TAKESHIMA, N., ISLAM, M. M., ROGERS, M. E., ROGERS, N. L., MOHAMMOD, M., LEE, S. & KOIZUMI, D. 2007. Functional fitness gain varies in older adults depending on exercise mode. *Medicine and Science in Sports and Exercise,* 39, 2036-2043.

TANG, Y., LOPEZ, I. & BALOH, R. W. 2001. Age-related change of the neuronal number in the human medial vestibular nucleus: A stereological investigation. *Journal of Vestibular Research-Equilibrium and Orientation,* 11, 357-363.

TAUBE, W., SCHUBERT, M., GRUBER, M., BECK, S., FAIST, M. & GOLLHOFER, A. 2006. Direct corticospinal pathways contribute to neuromuscular control of perturbed stance. *Journal of Applied Physiology,* 101, 420-429.

THIBAUD, M., BLOCH, F., TOURNOUX-FACON, C., BRÈQUE, C., RIGAUD, A. S., DUGUÉ, B. & KEMOUN, G. 2011. Impact of physical activity and sedentary behaviour on fall risks in older people: A systematic review and meta-analysis of observational studies. *European Review of Aging and Physical Activity*, (In Press).

THOM, D. 1998. Variation in estimates of urinary incontinence prevalence in the community: effects of differences in definition, population characteristics, and study type. *Journal of the American Geriatric Society,* 46, 473-480.

THOMAS, S., MACKINTOSH, S. & HALBERT, J. 2010. Does the 'Otago exercise programme' reduce mortality and falls in older adults?: A systematic review and meta-analysis. *Age and Ageing,* 39, 681-687.

THOMAS, S., READING, J. & SHEPHARD, R. J. 1992. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). *Canadian Journal of Sport Sciences-Revue Canadienne Des Sciences Du Sport,* 17, 338-345.

TIEDEMANN, A., SHERRINGTON, C., CLOSE, J. C. T. & LORD, S. R. Exercise and Sports Science Australia Position Statement on exercise and falls prevention in older people. *Journal of Science and Medicine in Sport*, 14, 489-495

TIERNEY, S., MAMAS, M., SKELTON, D., WOODS, S., RUTTER, M. K., GIBSON, M., NEYSES, L. & DEATON, C. 2011. What can we learn from patients with heart failure about exercise adherence? A systematic review of qualitative papers. *Health Psychology,* 30, 401-410.

TINETTI, M. 2003. Preventing falls in elderly persons. *New England Journal of Medicine,* 348, 42-49.

TINETTI, M. E. 1986. Performance-oriented assessment of mobility problems in elderly patients. *Journal of the American Geriatric Society,* 34, 119-26.

TINETTI, M. E., MENDES DE LEON, C. F., DOUCETTE, J. T. & BAKER, D. I. 1994. Fear of falling and fall-related efficacy in relationship to functioning among community-living elders. *Journals of Gerontology,* 49, M140-M147.

TINETTI, M. E., RICHMAN, D. & POWELL, L. 1990. Falls Efficacy as a measure of Fear of Falling. *Journals of Gerontology,* 45, P239-P243.

TINETTI, M. E. & WILLIAMS, C. S. 1998. The effect of falls and fall injuries on functioning in community- dwelling older persons. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 53, 112-119.

TOPP, R., MIKESKY, A., WIGGLESWORTH, J., HOLT, W., JR. & EDWARDS, J. E. 1993. The effect of a 12-week dynamic resistance strength training program on gait velocity and balance of older adults. *Gerontologist,* 33, 501-506.

TOPPER, A. K., MAKI, B. E. & HOLLIDAY, P. J. 1993. Are activity-based assessments of balance and gait in the elderly predictive of risk of falling and or type of fall. *Journal of the American Geriatrics Society,* 41, 479-487.

TROMP, A. M., PLUIJM, S. M., SMIT, J. H., DEEG, D. J., BOUTER, L. M. & LIPS, P. 2001. Fall-risk screening test: a prospective study on predictors for falls in community-dwelling elderly. *Journal of Clinical Epidemioliology* 54, 837-844.

TUCKER, P. & GILLILAND, J. 2007. The effect of season and weather on physical activity: A systematic review. *Public Health,* 121, 909-922.

UITENBROEK, D. G. 1993. Seasonal variation in leisure time physical activity. *Medicine and Science in Sports and Exercise,* 25, 755-760.

VAN DER BIJ, A. K., LAURANT, M. G. H. & WENSING, M. 2002. Effectiveness of physical activity interventions for older adults - A review. *American Journal of Preventive Medicine,* 22, 120-133.

VAN DER MEI, I., PONSONBY, A., ENGELSEN, O., PASCO, J. A., MCGRATH, J. J., EYLES, D. W., BLIZZARD, L., DWYER, T., LUCAS, R. & JONES, G. 2007. The high prevalence of vitamin D insufficiency across Australian populations is the only partly explained by season and latitude. *Environmental Health Perspectives,* 115, 1132-1139.

VAN NIEUWENHUIZEN, R. C., VAN DIJK, N., VAN BREDA, F. G., SCHEFFER, A. C., KOREVAAR, J. C., VAN DER CAMMEN, T. J., LIPS, P., GOSLINGS, J. C. & DE ROOIJ, S. E. 2010. Assessing the prevalence of modifiable risk factors in older patients visiting an ED due to a fall using the CAREFALL Triage Instrument. *American Journal of Emergency Medicine,* 28, 994-1001.

VEREECK, L., WUYTS, F., TRUIJEN, S. & DE HEYNING, P. V. 2008. Clinical assessment of balance: Normative data, and gender and age effects. *International Journal of Audiology,* 47, 67-75.

VIND, A. B., ANDERSEN, H. E., PEDERSEN, K. D., JOERGENSEN, T. & SCHWARZ, P. 2010. Effect of a program of multifactorial fall prevention on health-related quality of life, functional ability, fear of falling and psychological well-being. A randomised controlled trial. *Aging Clinical & Experimental Research,* 22, 249-254.

VISSER, J. E., CARPENTER, M. G., VAN DER KOOIJ, H. & BLOEM, B. R. 2008. The clinical utility of posturography. *Clinical Neurophysiology,* 119, 2424-2436.

VOLLMER, C. M., BOND, J., EDEN, B. M., RESCH, D. S., FULK, L., ROBINSON, S. & HUGHES, L. E. 2010. Incidence, prevalence, and under-recognition of delirium in urology patients. *Urologic Nursing,* 30, 235-241.

VOUKELATOS, A., CUMMING, R. G., LORD, S. R. & RISSEL, C. 2007. A randomised, controlled trial of Tai Chi for the prevention of falls: The central Sydney Tai Chi trial. *Journal of the American Geriatrics Society,* 55, 1185-1191.

WALKER, P. C., ALRAWI, A., MITCHELL, J. F., REGAL, R. E. & KHANDERIA, U. 2005. Medication use as a risk factor for falls among hospitalized elderly patients. *American Journal of Health-System Pharmacy,* 62, 2495-2499.

WALTHER, L. E., SCHAAF, H., SOMMER, D. & HORMANN, K. 2011. Air Conducted Ocular VEMP: I. Determination of a Method and Application in Normal Patients. *Laryngo-Rhino-Otologie,* 90, 410-415.

WASHBURN, R., MCAULEY, E., KATULA, J., MIHALKO, S. & BOILEAU, R. 1999. The physical activity scale for the elderly (PASE): Evidence for validation. *Journal of Clinical Epidemiology,* 52, 643-651.

WASHBURN, R., SMITH, K., JETTE, A. & JANNEY, C. 1993. The physical activity scale for the elderly (PASE): Development and evaluation. *Journal of Clinical Epidemiology,* 46, 153-162.

WASHBURN, R. A. & FICKER, J. L. 1999. Physical Activity Scale for the Elderly (PASE): the relationship with activity measured by a portable accelerometer. *Journal of Sports Medicine and Physical Fitness,* 39, 336-340.

WEBB, A., KLINE, L. & HOLICK, M. 1988. Influence of season and latitude on the cutaneous synthesis of vitamin D3: Exposure to winter sunlight in Boston and Edmonton will not promote vitamin D3 synthesis in human skin. *Journal of Clinical Endocrinology & Metabolism,* 67, 373-378.

WEHREN, L., HAWKES, W., ORWIG, D., HEBEL, J., ZIMMERMAN, S. & MAGAZINER, J. 2003. Gender differences in mortality after hip fracture; the role of infection. *Journal of Bone and Mineral Research,* 18, 2231-2237.

WESTHOFF, M. H., STEMMERIK, L. & BOSHUIZEN, H. C. 2000. Effects of a low-intensity strength-training program on knee-extensor strength and functional ability of frail older people. *Journal of Aging and Physical Activity,* 8, 325-342.

WHITNEY, S. L., WRISLEY, D. M., MARCHETTI, G. F., GEE, M. A., REDFERN, M. S. & FURMAN, J. M. 2005. Clinical measurement of sit-to-stand performance in people with balance disorders: validity of data for the Five-Times-Sit-to-Stand Test. *Physical Therapy,* 85, 1034-1045.

WHOOLEY, M. A., KIP, K. E., CAULEY, J. A., ENSRUD, K. E., NEVITT, M. C. & BROWNER, W. S. 1999. Depression, falls, and risk of fracture in older women. Study of Osteoporotic Fractures Research Group. *Archives of Internal Medicine,* 159, 484-490.

WOLF, S., BARNHART, H. & KUTNER, N. 1996. Reducing frailty and falls in older persons: an investigation of Tai Chi and computerized balance training. *Journal of American Geriatric Society,* 44, 489-497.

WOLFSON, L., JUDGE, J., WHIPPLE, R. & KING, M. 1995. Strength is a major factor in balance, gait, and the occurrence of falls. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 50, 64-67.

WOLFSON, L., WHIPPLE, R., DERBY, C., JUDGE, J., KING, M., AMERMAN, P., SCHMIDT, J. & SMYERS, D. 1996. Balance and strength training in older adults: Intervention gains and Tai Chi maintenance. *Journal of the American Geriatrics Society,* 44, 498-506.

WOLFSON, L. I., WHIPPLE, R., AMERMAN, P. & KLEINBERG, A. 1986. Stressing the postural response. A quantitative method for testing balance. *Journal of the American Geriatrics Society,* 34, 845-850.

WOOD, K., EDWARDS, J., CLAY, O., WADLEY, V., ROENKER, D. & BALL, K. 2005. Sensory and cognitive factors influencing functional ability in older adults. *Gerontology,* 51, 131-141.

WOOLCOTT, J. C., RICHARDSON, K. J., WIENS, M. O., PATEL, B., MARIN, J., KHAN, K. M. & MARRA, C. A. 2009. Meta-analysis of the impact of 9 medication classes on falls in elderly persons. *Archives of Internal Medicine,* 169, 1952-1960.

WOOLLEY, S. M., CZAJA, S. J. & DRURY, C. G. 1997. An assessment of falls in elderly men and women. *Journals of Gerontology Series A, Biological Sciences and Medical Sciences,* 52, M80-M87.

WWW.WHO.INT/VIOLENCE_INJURY_PREVENTION/UNINTENTIONAL_INJURIES/FALLS/FALLS1/EN.

YANG, X. J., HILL, K., MOORE, K., WILLIAMS, S., DOWSON, L., BORSCHMANN, K., SIMPSON, J. A. & DHARMAGE, S. C. 2011. Effectiveness of a targeted exercise intervention in reversing older people's mild balance dysfunction: A randomised controlled trial. *Physical Therapy*, 92, 24-37.

YARDLEY, L., BEYER, N., HAUER, K., KEMPEN, G., PIOT-ZIEGLER, C. & TODD, C. 2005. Development and initial validation of the Falls Efficacy Scale-International (FES-I). *Age and Ageing,* 34, 614-619.

YASUMURA, S., HAGA, H., NAGAI, H., SUZUKI, T., AMANO, H. & SHIBATA, H. 1994. Rate of falls and the correlates among elderly people living in an urban community in Japan. *Age and Ageing,* 23, 323-327.

YEUNG, P. Y., CHAU, P. H., WOO, J., YIM, V. W. T. & RAINER, T. H. 2011. Higher incidence of falls in winter among older people in Hong Kong. *Journal of Clinical Gerontology and Geriatrics,* 2, 13-16.

ZIJLSTRA, A., UFKES, T., SKELTON, D. A., LUNDIN-OLSSON, L. & ZIJLSTRA, W. 2008. Do dual tasks have an added value over single tasks for balance assessment in fall prevention programs? A mini-review. *Gerontology,* 54, 40-49.

ZIJLSTRA, G. A. R., VAN HAASTREGT, J. C. M., VAN EIJK, J. T. M., VAN ROSSUM, E., STALENHOEF, P. A. & KEMPEN, G. 2007. Prevalence and correlates of fear of falling, and associated avoidance of activity in the general population of community-living older people. *Age and Ageing,* 36, 304-309.

ZUR, O., BERNER, Y. N. & CARMELI, E. 2006. Correlation between vestibular function and hip fracture following falls in the elderly: a case-controlled study. *Physiotherapy,* 92, 208-213.

11 APPENDICES (AVAILABLE IN DIGITAL FILES)

11.1 *Questionnaires*

- 1a Physical Activity Scale in the Elderly
- 1b Community Healthy Activities Model Program for Seniors, including Sun Exposure and Skin Protection Behaviour Questionnaire
- 1c Physical Activity Readiness Questionnaire

11.2 *Guidelines*

ACSM Guidelines for Exercise and Physical Activity for Older Adults

SUBJECT ID:____________

LEISURE TIME ACTIVITY

1. Over the past 7 days, how often did you participate in sitting activities such as reading, watching TV or doing handcrafts?

[0] NEVER	[1] SELDOM	[2] SOMETIMES	[3] OFTEN
GO TO **Q #2**	(1-2 DAYS)	(3-4 DAYS)	(5-7 DAYS)

1.a. What were these activities?

1.b. On average, how many hours per day did you engage in these sitting activities?

[1] LESS THAN 1 [2] 1- 2 [3] 2- 4 [4] MORE THAN 4

2. Over the past 7 days, how often did you take a walk outside your home or yard for any reason? For exaple, for fun or exercise, walking to work, walking the dog, etc.

[0] NEVER	[1] SELDOM	[2] SOMETIMES	[3] OFTEN
GO TO **Q #3**	(1-2 DAYS)	(3-4 DAYS)	(5-7 DAYS)

2.a. On average, how many hours per day did you spend walking?

[1] LESS THAN 1 [2] 1- 2 [3] 2- 4 [4] MORE THAN 4

3. Over the past 7 days, how often did you engage in LIGHT sport or recreational activities such as bowling, golf with a cart, fishing from a boat or pier or other similar activity?

[0] NEVER	[1] SELDOM	[2] SOMETIMES	[3] OFTEN
GO TO **Q #4**	(1-2 DAYS)	(3-4 DAYS)	(5-7 DAYS)

3.a. What were these activities?

3.b. On average, how many hours per day did you engage in these light sport or recreational activities?

[1] LESS THAN 1 [2] 1- 2 [3] 2- 4 [4] MORE THAN 4

4. Over the past 7 days, how often did you engage in MODERATE sport or recreational activities such as doubles tennis, ballroom dancing, golf, or other similar activity?

[0] NEVER GO TO **Q #5**	[1] SELDOM (1-2 DAYS)	[2] SOMETIMES (3-4 DAYS)	[3] OFTEN (5-7 DAYS)

4.a. What were these activities?

4.b. On average, how many hours per day did you engage in these moderate sport or recreational activities?

[1] LESS THAN 1 [2] 1- 2 [3] 2- 4 [4] MORE THAN 4

5. Over the past 7 days, how often did you engage in STRENUOUS sport or recreational activities such as jogging, swimming, cycling, singles tennis, aerobic dance or other similar activity?

[0] NEVER GO TO **Q #6**	[1] SELDOM (1-2 DAYS)	[2] SOMETIMES (3-4 DAYS)	[3] OFTEN (5-7 DAYS)

5.a. What were these activities?

5.b. On average, how many hours per day did you engage in these strenuous sport or recreational activities?

[1] LESS THAN 1 [2] 1- 2 [3] 2- 4 [4] MORE THAN 4

6. Over the past 7 days, how often did you do any exercises specifically to increase muscle strength and endurance, such as lifting weights or pushups etc.?

[0] NEVER GO TO **Q #7**	[1] SELDOM (1-2 DAYS)	[2] SOMETIMES (3-4 DAYS)	[3] OFTEN (5-7 DAYS)

6.a. What were these activities?

6.b. On average, how many hours per day did you engage in these strenuous sport or recreational activities?

[1] LESS THAN 1 [2] 1- 2 [3] 2- 4 [4] MORE THAN 4

HOUSEHOLD ACTIVITY

7. During the past 7 days, have you done any light housework, such as, dusting or washing dishes?

[1] NO [2] YES

8. During the past 7 days, have you done any heavy housework, such as vacuuming, scrubbing floors, washing windows, or carrying wood?

[0] NO [1] YES

9. During the past 7 days, did you engage in any of the following activities?

	NO	YES
a. Home repairs, such as painting, wallpapering, etc.	0	1
b. Lawn work or yard care, such as leaf removal, wood chopping, etc.	0	1
c. Outdoor gardening	0	1
d. Caring for another person, such as children, dependent spouse, or another adult	0	1

CONTINUED OVER THE PAGE ....

WORK-RELATED ACTIVITY

10. During the past 7 days, did you work for pay or as a volunteer?

[0] NO [1] YES

10. a. How many hours work did you do in the last 7 days?

10. b. Which of the following categories best describes the amount of physical activity required on your job?

[1] Mainly sitting with slight arm movements

[2] Sitting or standing with some walking

[3] Walking, with some handling of materials generally weighing less than 25kg

[4] Walking and heavy manual work often required handling of materials weighing over 25kg

CHAMPS Activities Questionnaire for Older Adults

Date:________________________________

Name or ID:__________________________

CHAMPS: Community Healthy Activities Model Program for Seniors
Institute for Health & Aging, University of California San Francisco
Stanford Center for Research in Disease Prevention, Stanford University

Contact: Anita L. Stewart, Ph.D., UCSF, anitast@itsa.ucsf.edu

This questionnaire is about activities that you may have done in the past 4 weeks. The questions on the following pages are similar to the example shown below.

INSTRUCTIONS

If you DID the activity in the past 4 weeks:

Step #1 Check the YES box.

Step #2 Think about <u>how many</u> TIMES <u>a week</u> you usually did it, and write your response in the space provided.

Step #3 Circle how many TOTAL HOURS <u>in a typical week</u> you did the activity.

Here is an example of how Mrs. Jones would answer question #1: Mrs. Jones usually visits her friends Maria and Olga <u>twice a week</u>. She usually spends <u>one</u> hour on Monday with Maria and <u>two</u> hours on Wednesday with Olga. Therefore, the total hours a week that she visits with friends is <u>3</u> hours a week.

In a typical week during the past 4 weeks, did you…							
1. Visit with friends or family (other than those you live with)? ☒ **YES** How many TIMES a week? 2 ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

If you DID NOT do the activity:

- **Check the NO box and move to the next question**

In a typical week during the past 4 weeks, did you …							
1. Visit with friends or family (other than those you live with)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
2. Go to the senior center? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
3. Do volunteer work? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
4. Attend church or take part in church activities? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
5. Attend other club or group meetings? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
6. Use a computer? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …							
7. Dance (such as square, folk, line, ballroom) (do not count aerobic dance here)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
8. Do woodworking, needlework, drawing, or other arts or crafts? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
9. Play golf, carrying or pulling your equipment (count walking time only)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
10. Play golf, riding a cart (count walking time only)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
11. Attend a concert, movie, lecture, or sport event? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
12. Play cards, bingo, or board games with other people? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …								
13. Shoot pool or billiards? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
14. Play singles tennis (do not count doubles)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
15. Play doubles tennis (do not count singles)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
16. Skate (ice, roller, in-line)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
17. Play a musical instrument? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
18. Read? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
19. Do heavy work around the house (such as washing windows, cleaning gutters)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …							
20. Do light work around the house (such as sweeping or vacuuming)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
21. Do heavy gardening (such as spading, raking)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
22. Do light gardening (such as watering plants)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
23. Work on your car, truck, lawn mower, or other machinery? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
****Please note: For the following questions about running and walking, include use of a treadmill.**							
24. Jog or run? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
25. Walk uphill or hike uphill (count only uphill part)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …							
26. Walk <u>fast or briskly</u> for exercise (do <u>not</u> count walking leisurely or uphill)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
27. Walk <u>to do errands</u> (such as to/from a store or to take children to school <u>(count walk time only)</u>? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
28. Walk <u>leisurely</u> for exercise or pleasure? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
29. Ride a bicycle or stationary cycle? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
30. Do other aerobic machines such as rowing, or step machines (do <u>not</u> count treadmill or stationary cycle)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
31. Do water exercises (do <u>not</u> count other swimming)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …							
32. Swim moderately or fast? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
33. Swim gently? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
34. Do stretching or flexibility exercises (do not count yoga or Tai-chi)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
35. Do yoga or Tai-chi? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
36. Do aerobics or aerobic dancing? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
37. Do moderate to heavy strength training (such as hand-held weights of more than 5 lbs., weight machines, or push-ups)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …							
38. Do light strength training (such as hand-held weights of 5 lbs. or less or elastic bands)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
39. Do general conditioning exercises, such as light calisthenics or chair exercises (do not count strength training)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
40. Play basketball, soccer, or racquetball (do not count time on sidelines)? ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
41. Spend time outside _________________________ ☐ **YES** How many TIMES a week?_____ ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

Sun protection patterns Do you ALWAYS (score 1), SOMETIMES (score 2) or NEVER (score 3) for the following questions

Use sunscreen _______
Wear a Hat _______
Avoid sun between 10am and 3pm _______
Wear clothing to protect you from the sun _______

Thank You

UTAS

University of Tasmania

School of Human Life Sciences

Physical Activity Readiness Questionnaire (PARQ)

For most people, physical activity should not present any problem or hazard. The PARQ has been designed to identify the small number of adults for whom physical activity might be inappropriate and those who should have medical advice concerning the type of activity most suitable. If you are over 69 years of age, and you are not used to being very active, check with your doctor before beginning to exercise.

Date:……………………….

Client:…………………………………………….

Circle the correct answer

1.	Has a doctor ever said that you have a heart condition and that you should only do physical exercise recommended by a doctor?	Yes/No
2.	Do you feel pain in your chest when you do physical activity?	Yes/No
3.	In the past month, have you had chest pain when you were not doing physical activity?	Yes/No
4.	Do you lose your balance because of dizziness or do you ever lose consciousness?	Yes/No
5.	Do you have a bone or joint problem that could be made worse by a change in your physical activity?	Yes/No
6.	Is your doctor currently prescribing drugs (eg. water pills) for your blood pressure or heart condition?	Yes/No
7.	Do you know of any other reason you should not do physical activity?	Yes/No
8.	Are you over a male over 45 or a female over 55?	Yes/No

Clinician's Name: ………………………..

Clinician's Signature: ………………………..

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